Outlook for Upsilon Measurements in sPHENIX

Outline: ● Motivation ● Experiment Design ● Projections

Jin Huang (BNL)

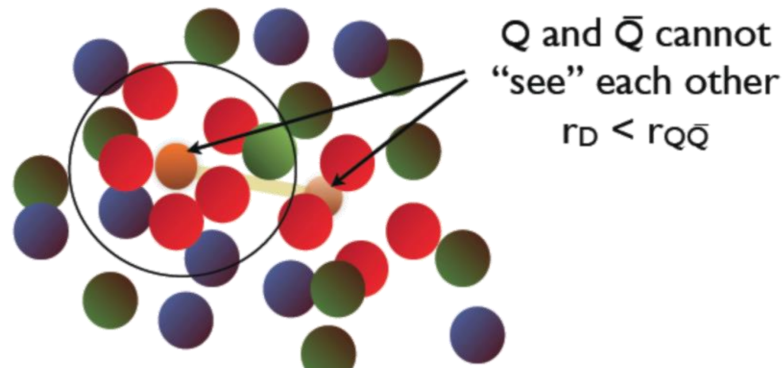
for the PHENIX collaboration

http://www.phenix.bnl.gov/plans

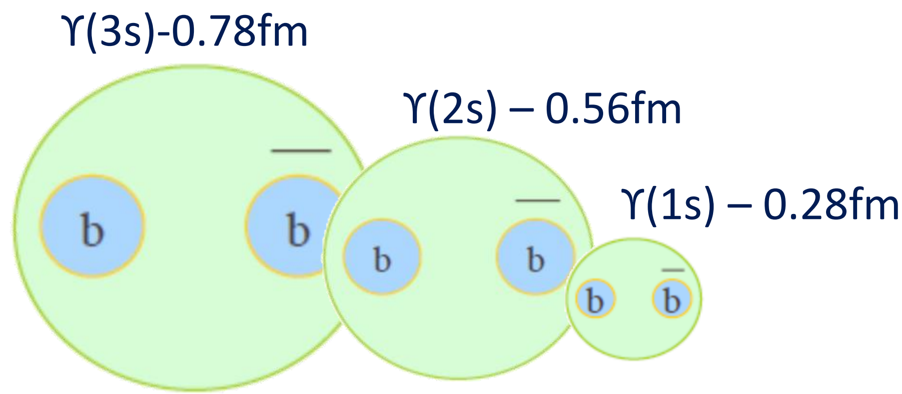
PHENIX

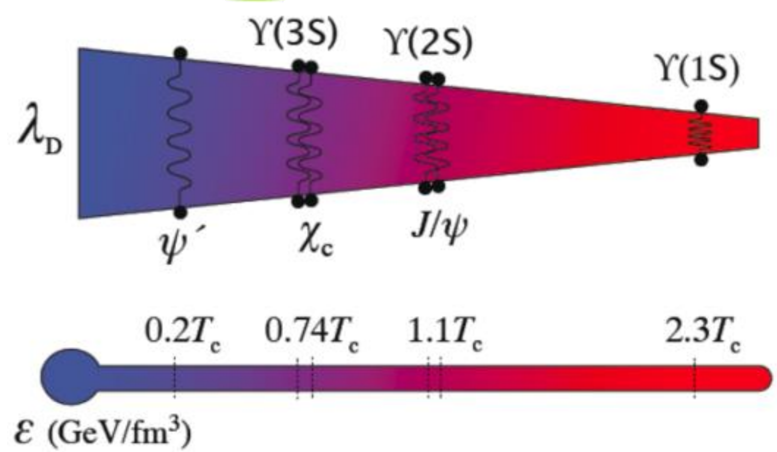
Physics case

- Heavy-quark-onion states:
  Probes QGP with different length binding strength
  Thermometer for QGP
- Also access to (and complicated by) nPDF, energy loss, Cronin eff., coalescence, final state break up, feed down …
- Advantages of Upsilons
  - Heavier quark, cleaner theoretical treatment, lower regeneration and CNM eff.
  - Three states of Upsilon mesons are sensitive to very different distance and binding strength



Courtesy from A. Mocsy

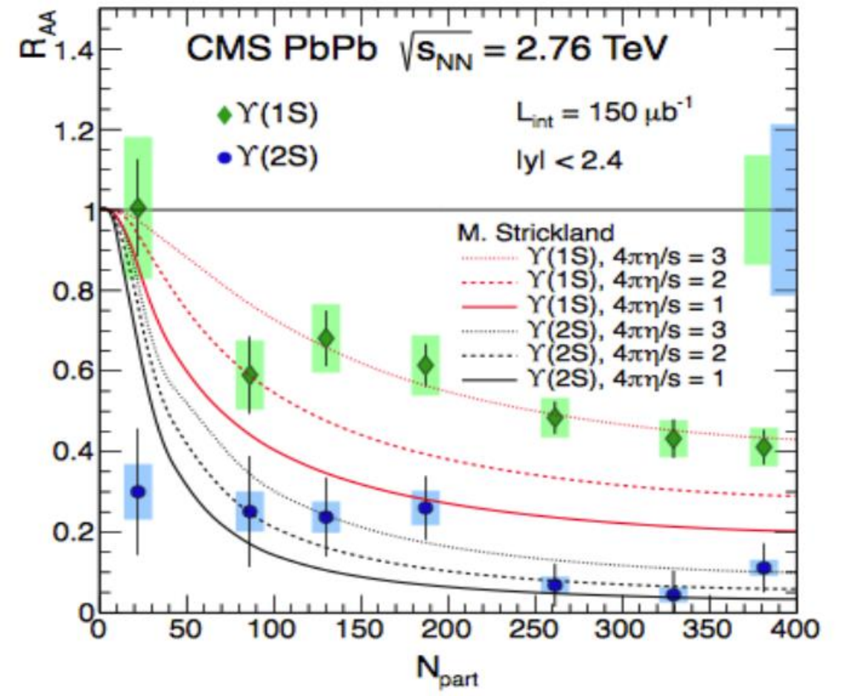




Selected World Data

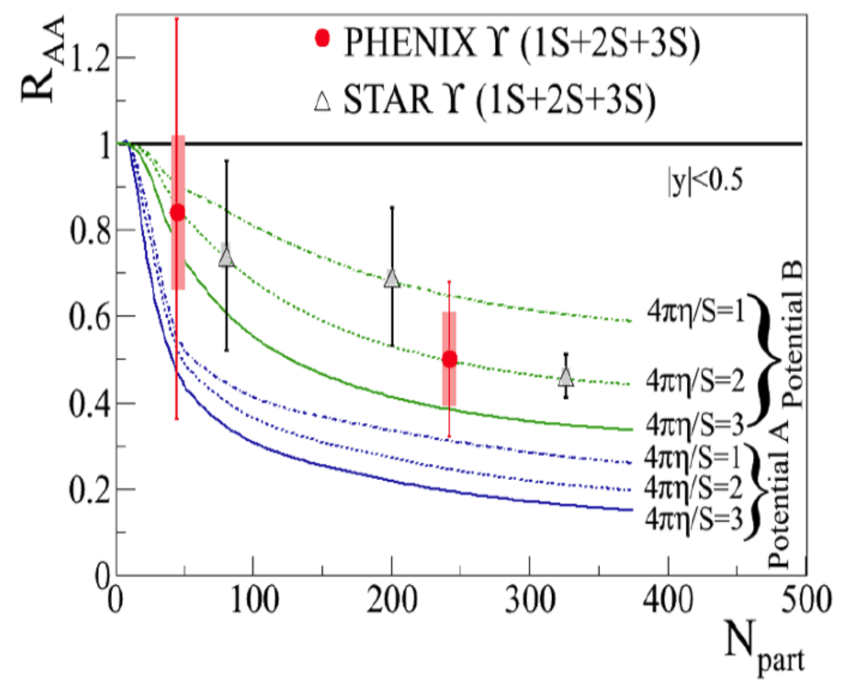
See also morning talks of Melynda, Manuel, Georg

PRL109(2012)222301



3S state completely melted in LHC energy

arXiv:1404.2246
PLB735(2014)127



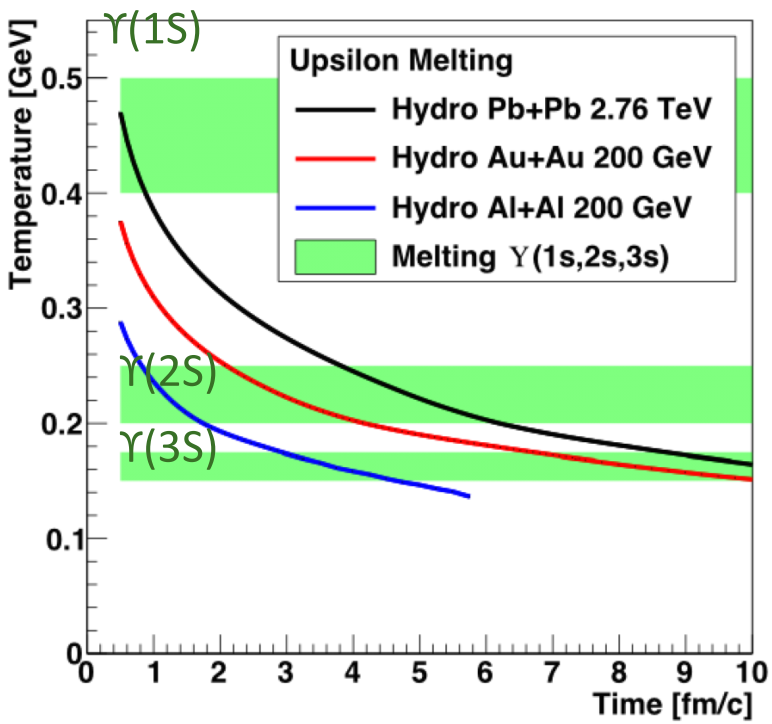
No separation in states yet

LHC 2.76TeV Pb+Pb

RHIC 200 GeV Au+Au

Three-states-separated High Precision Measurement Needed at RHIC

- QGP at close to T_C at RHIC, complementary to LHC
- Lower bottom production rate at RHIC leads to much smaller coalescence for ϒ production, clean access to color screening and CNM eff.
- Study of coalescence by compare separated- ϒ(2S)-state in comparison to J/ψ yield
- STAR/MTD detector, fully operational in Run14, will first extract 3-states yield at RHIC through fitting (see *Manuel's* talk).
  sPHENIX will provide much better resolution of three states and ~x10 acceptance

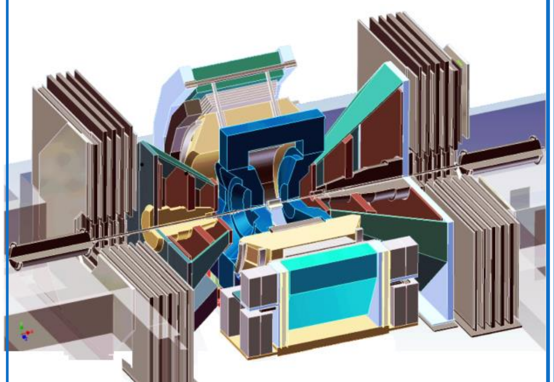


Overview of PHENIX Long-term Upgrades

Documented: http://www.phenix.bnl.gov/plans.html

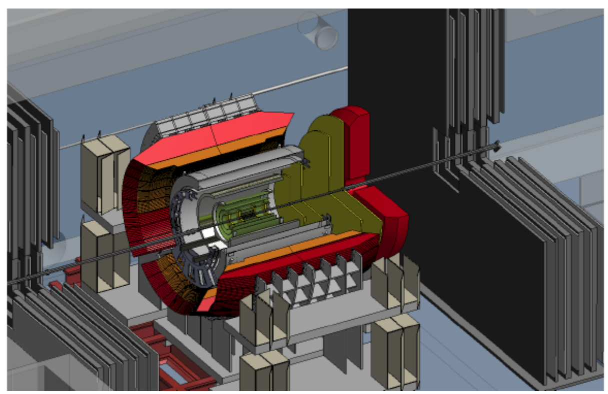
Current PHENIX

- 14y+ operation
  100+M$ investment
- 140+ published papers to date
- WWND Talks: Dion, Brooks, Bazilevsky, Sharma, Stankus, Todoroki
- Last run in this form 2016



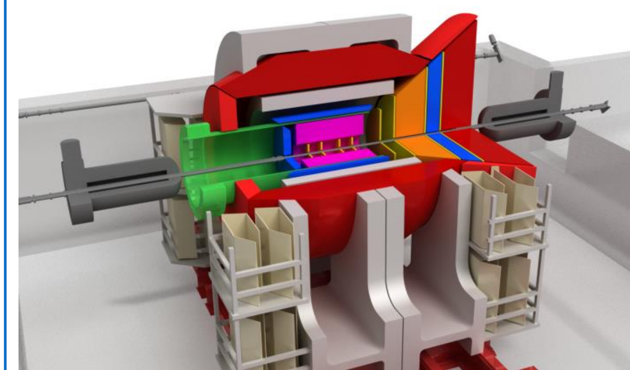
*s*PHENIX (+fsPHENIX)

- Comprehensive central upgrade base on BaBar magnet
- fsPHENIX : forward tracking, Hcal and muon ID
- WWND talk:
  Huang, Perepelitsa



An EIC detector

- Path of PHENIX upgrade leads to a capable EIC detector
- Large coverage of tracking, calorimetry and PID
- Open for new collaboration/new ideas
- Ref: arXiv:1406.2980 [hep-ex]

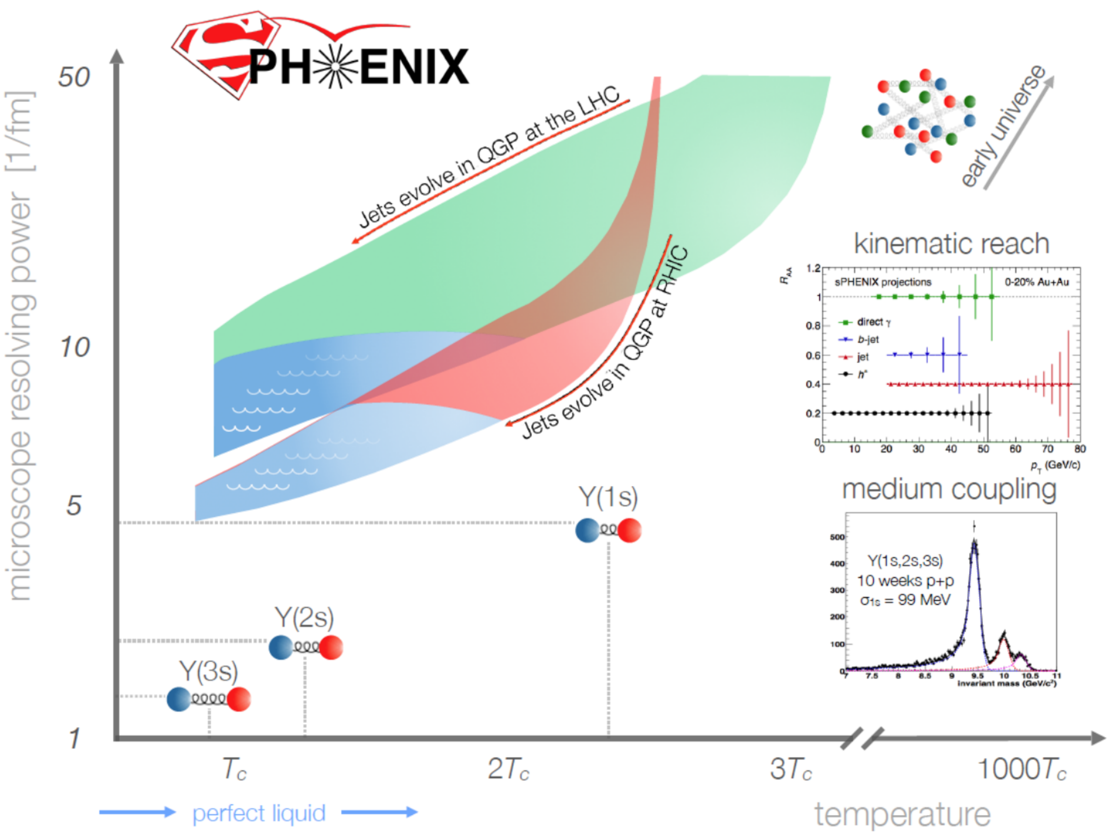


~2000 | 2017→2020 | ~2025 | Time

RHIC: A+A, spin-polarized p+p, spin-polarized p+A

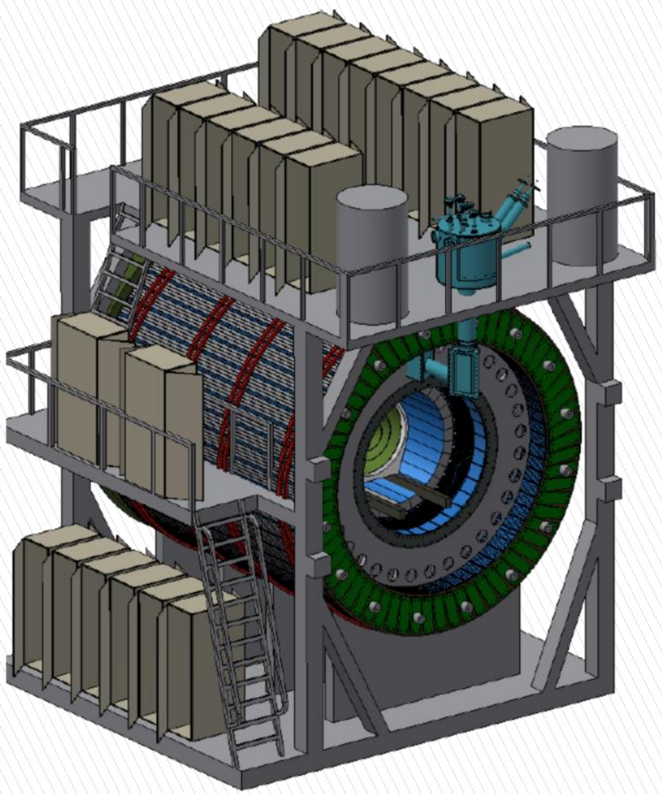
eRHIC: e+p, e+A

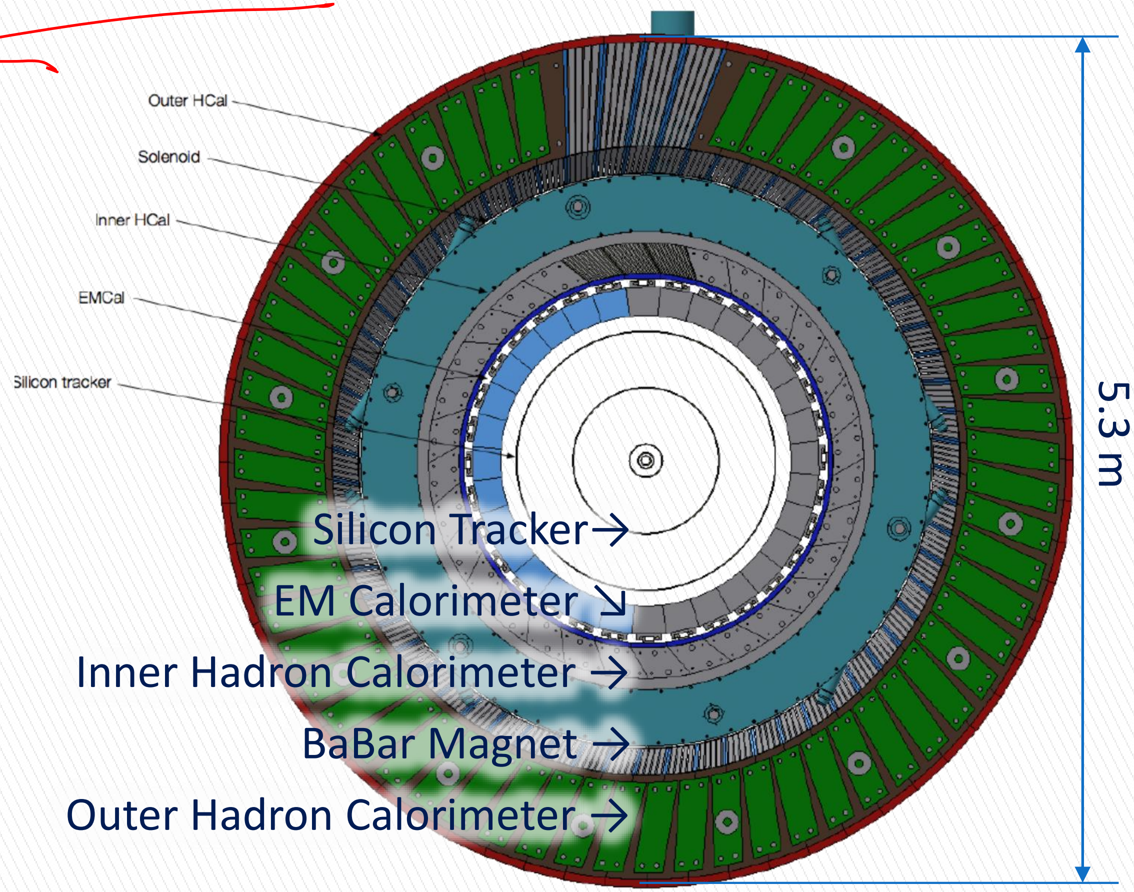
sPHENIX Physics Program



- Detailed inspection of QGP near T_c using probes over a broad range of scales
  - Jet and Di-jet
  - γ-jet correlations
  - Heavy flavor jets
    Talk: Thu, Perepelitsa
  - Separated ϒ(1s), ϒ(2s), ϒ(3s)
    This talk
- Positive DOE scientific review July 2014. Address the recommendation in 2014-Temple Hot-QCD town meeting
- Forward program in development (spin, CNM)
- Foundation to an EIC detector

sPHENIX experiment





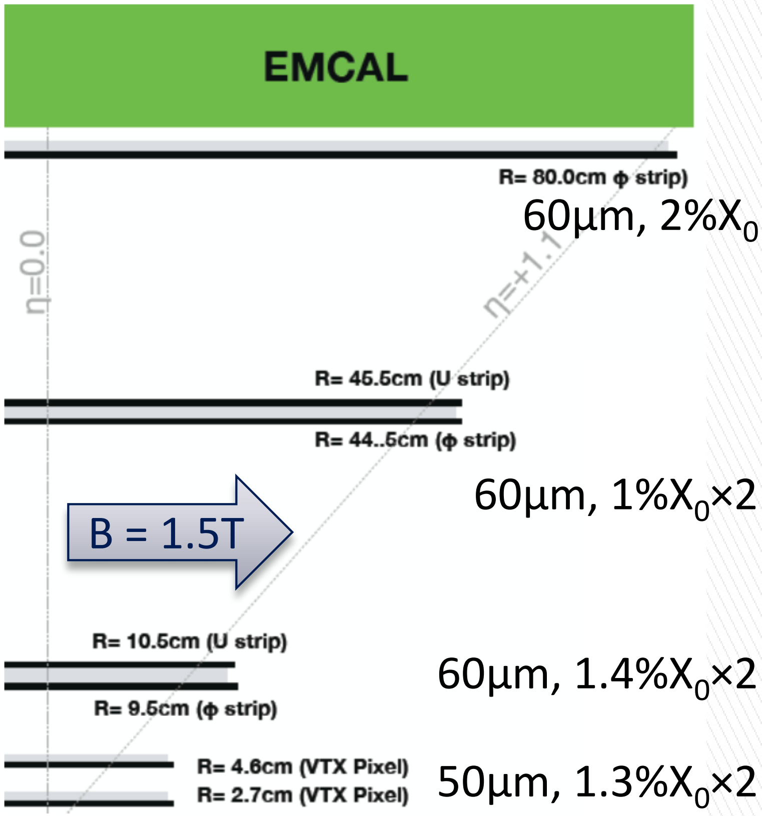
Detailed CAD model

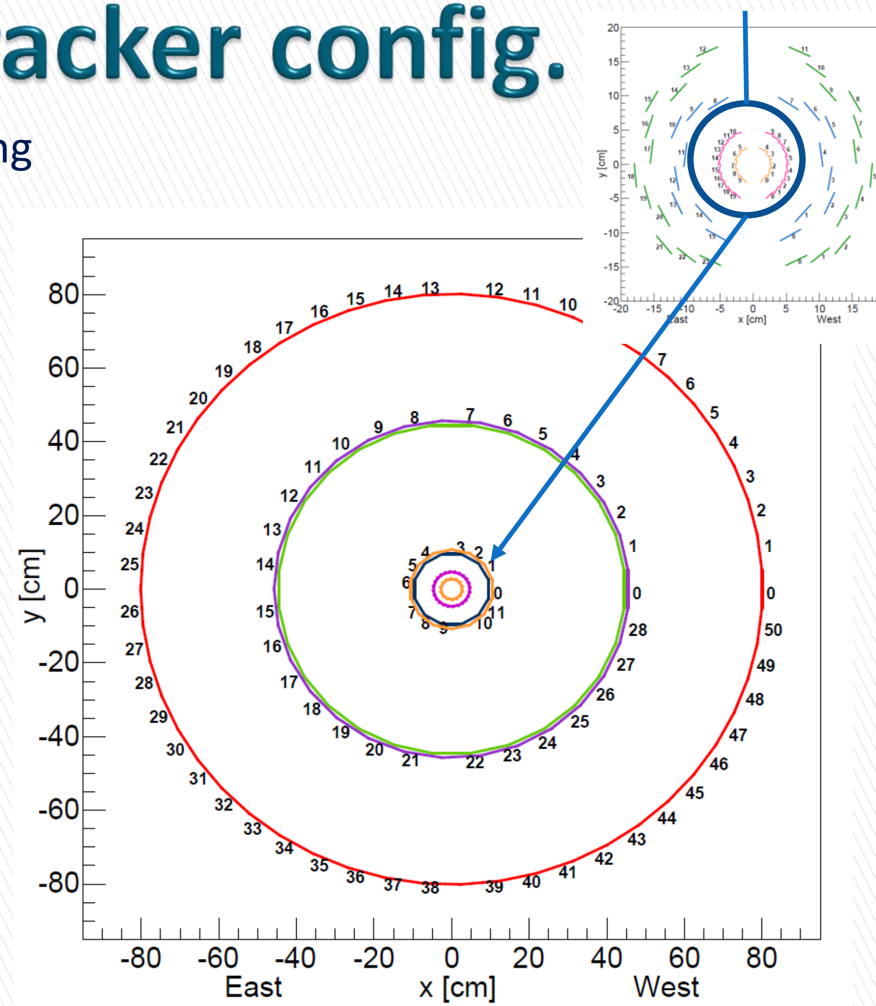
Beam view

Restacking PHENIX Pixel Tracker

Tracking : Silicon tracker config.

Also in study: a TPC for outer layer tracking

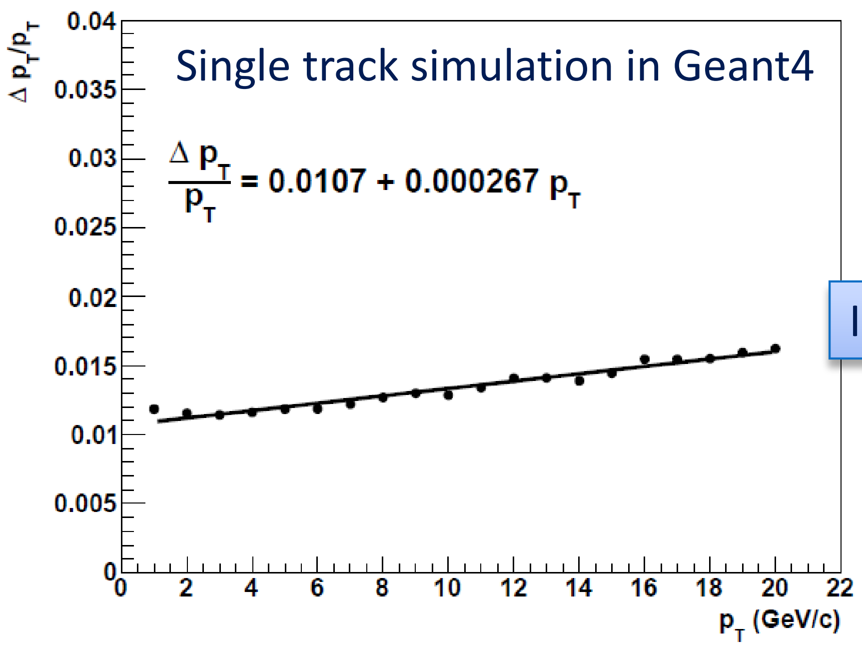




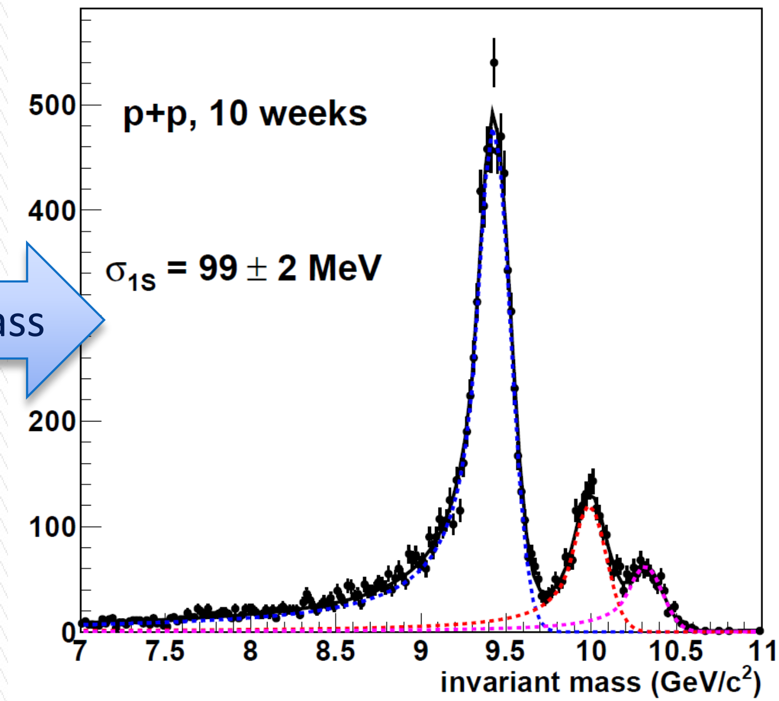
Side view

Beam View

Tracking : Performance in Geant4



Inv. Mass



Also full detector HIJING simulation in Geant4
Eff. = 92% at 1 GeV/c and 97% at high p_T.

Single track performance

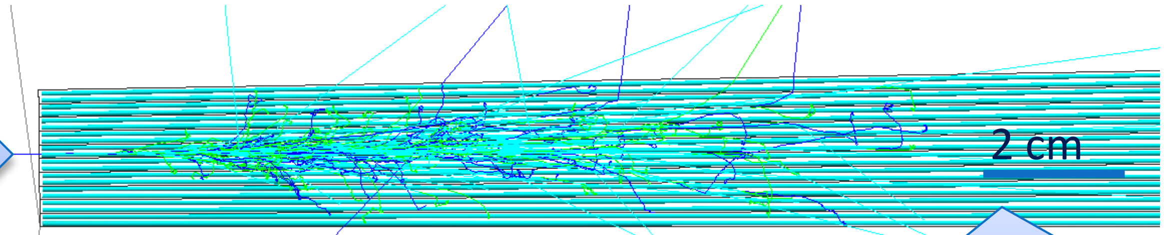
Invariant mass for e^+e^- pairs

Electron ID: EM Calorimeter

- Electron ID using a compact EMCal with assistance from inner HCal
- Scintillation fiber-W powder sampling calorimeter (SPACAL) used in reference design, $dE/E \sim 12\%/\sqrt{E}$
  R_M~2 cm, X_0~0.7 cm, critical for background reduction in AA collisions
- Covered full azimuthal and $|\eta|<1.1$ in sPHENIX

Side view

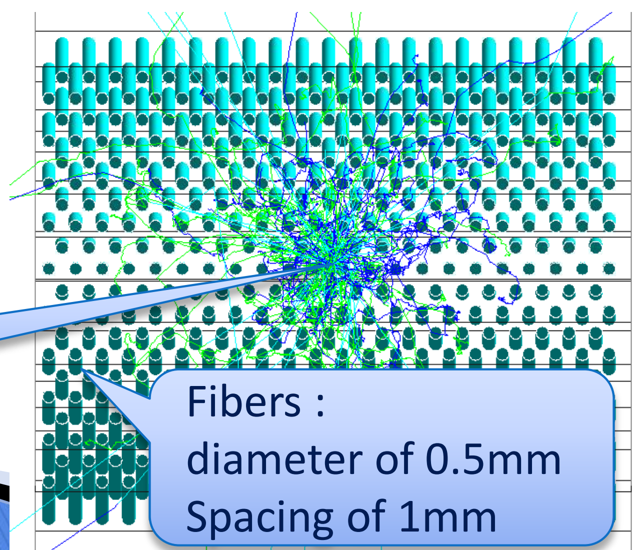
10GeV, e+



Tapered to form full cylinder
Azimuthally projective fibers

Particle view

1 cm



10GeV e+

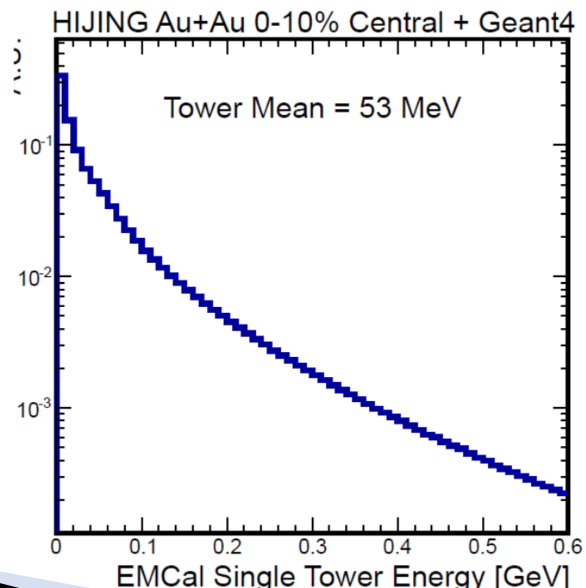
Fibers :
diameter of 0.5mm
Spacing of 1mm

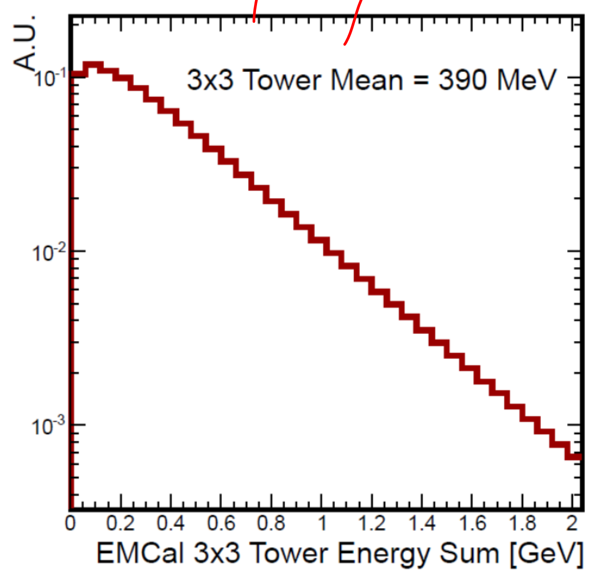
SPACAL prototypes from Oleg (UCLA)

Electron ID: HIJING event in Geant4

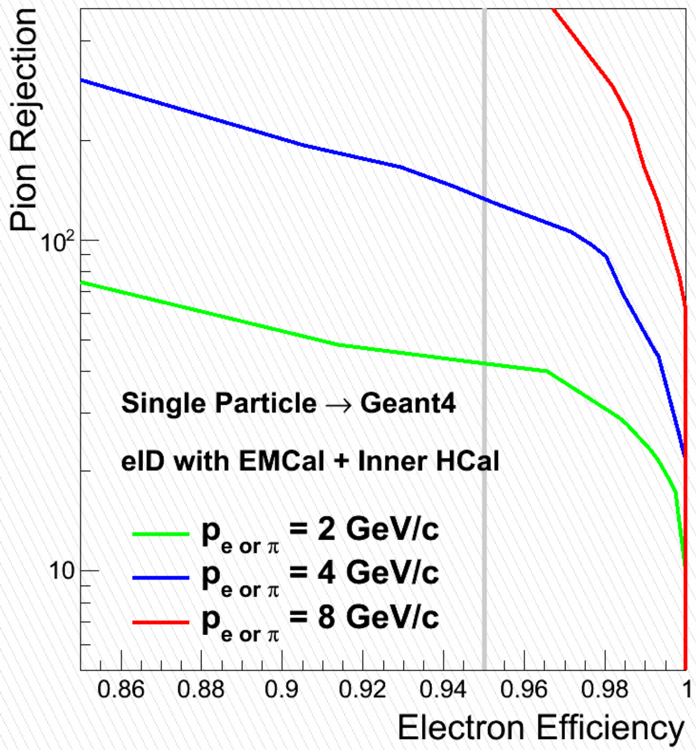
- Large scale HIJING+Geant4 simulation performed with detailed implementation of calorimeters
  22M scintillation fibers with thousands of particle showers in each Geant4 event
- Event background distribution in Central AuAu, showing background for electron ID under control thanks to the high density EM calorimeter.

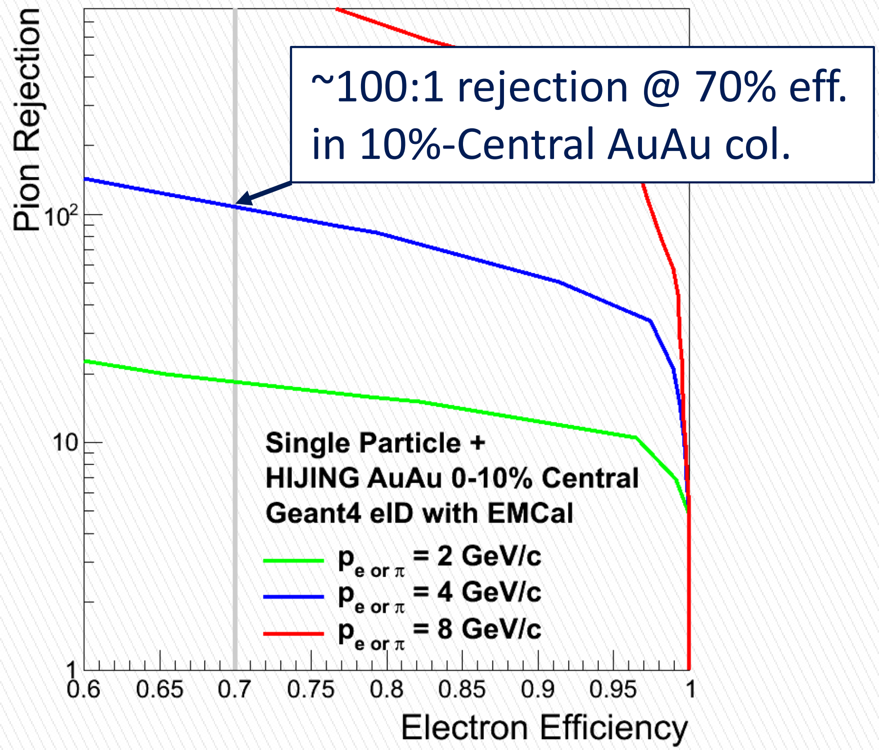
0,024 x 0,024, δη x δφ





Electron ID: Single track performance

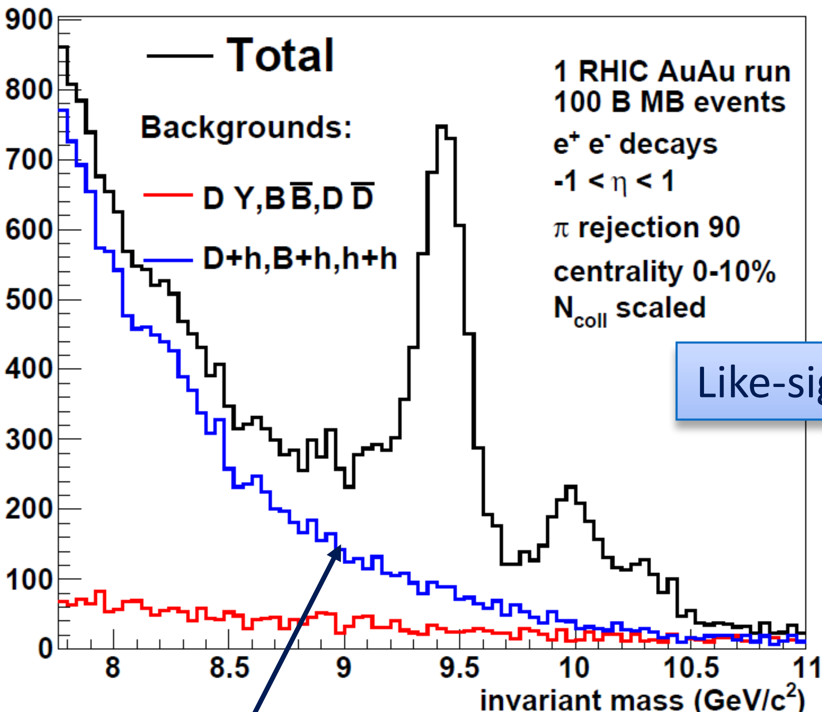




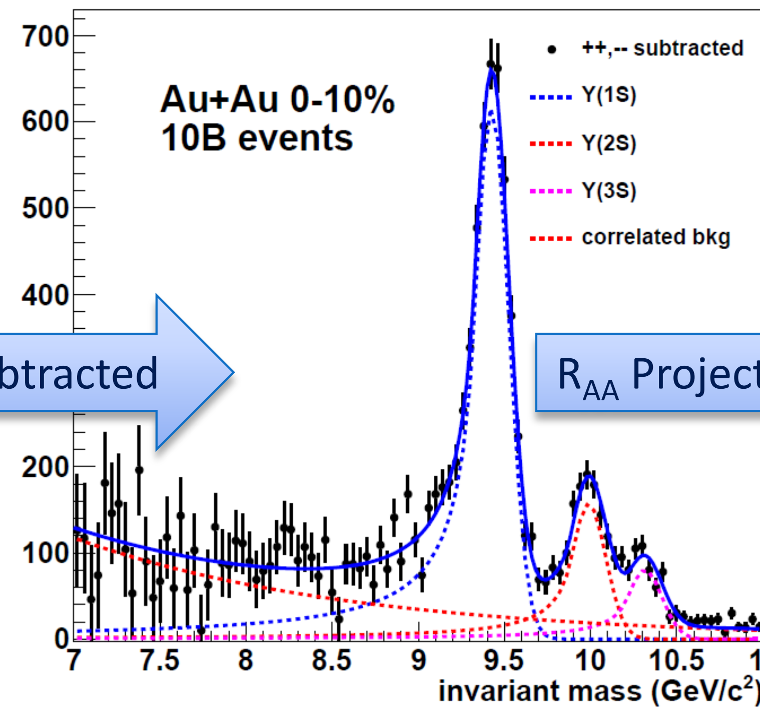
pp/ep electron ID
(EMC+HCAL)

10%-Central AA electron ID
(EMC Only)

Electron ID:
Performance in identified e^+e^- pairs



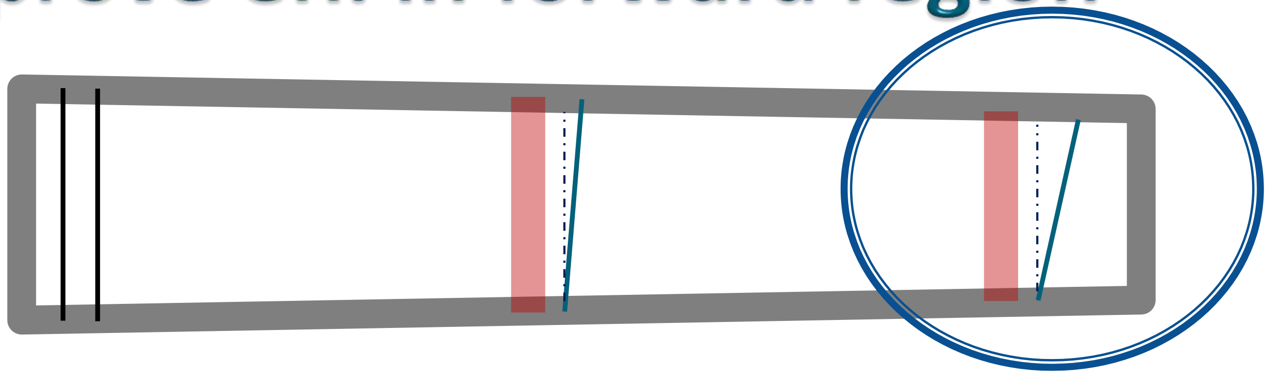
Like-sign subtracted

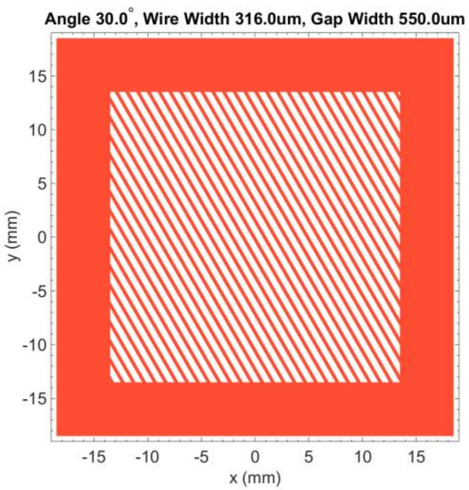


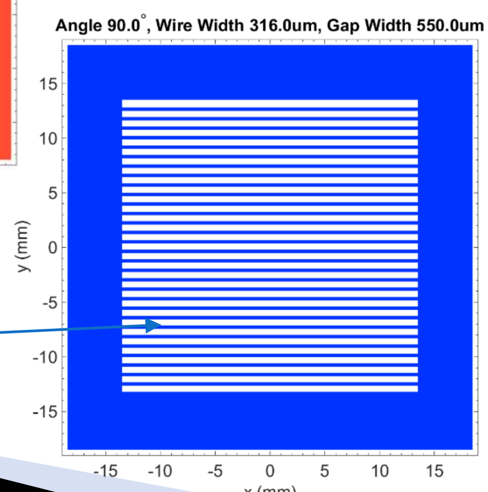
R_{AA} Projections

Background of mis-identified hadron

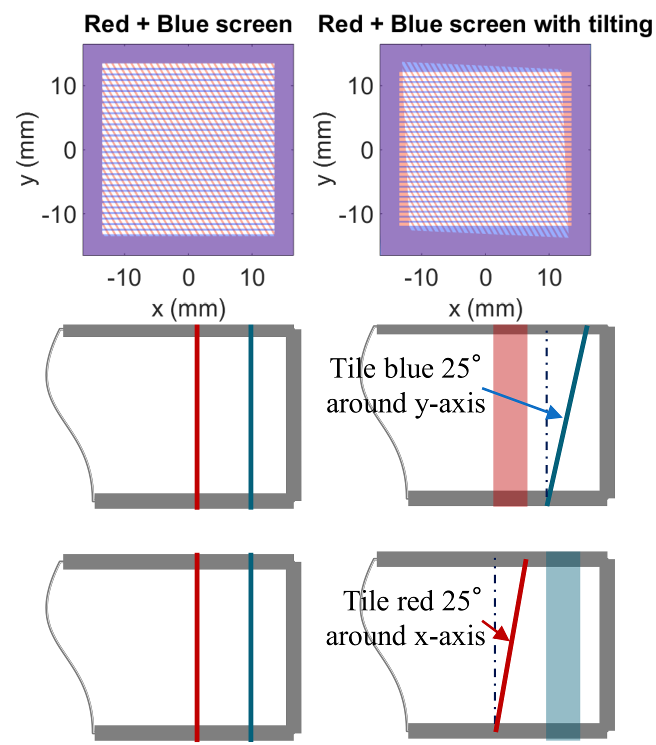
Recent R&D: fully projective SPACAL further improve eff. in forward region



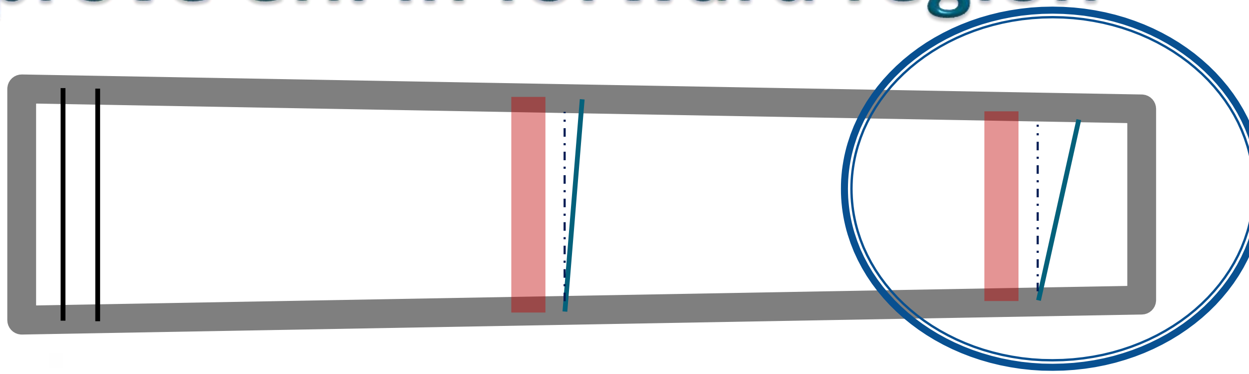


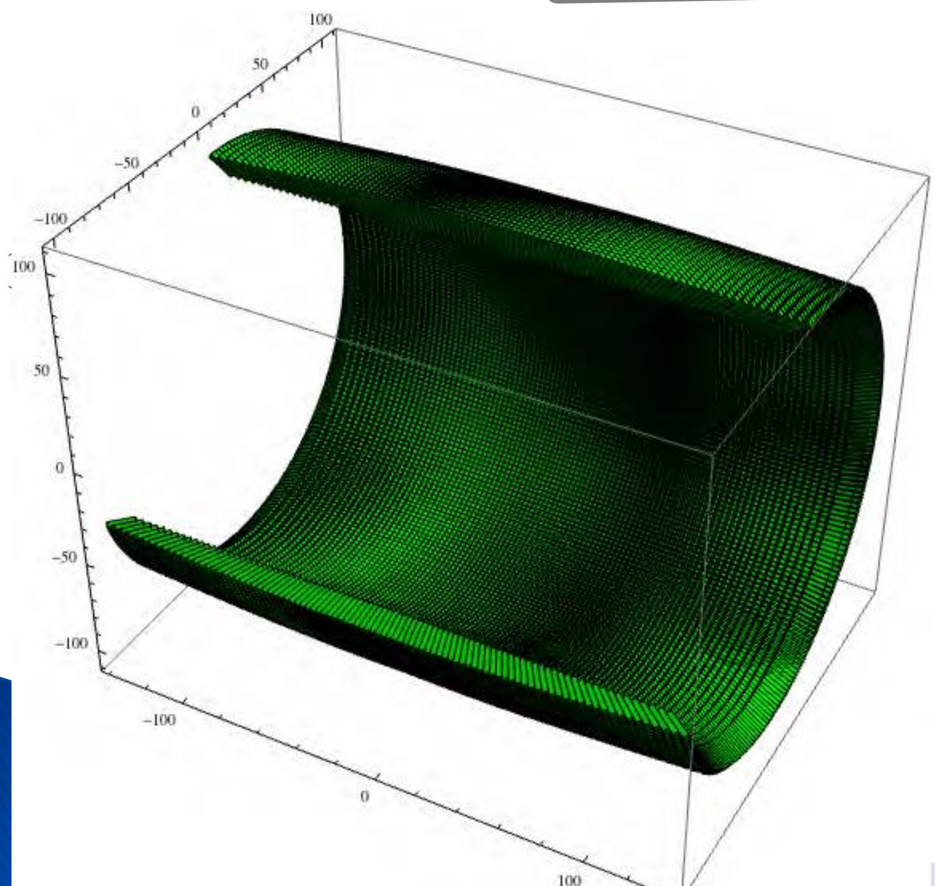


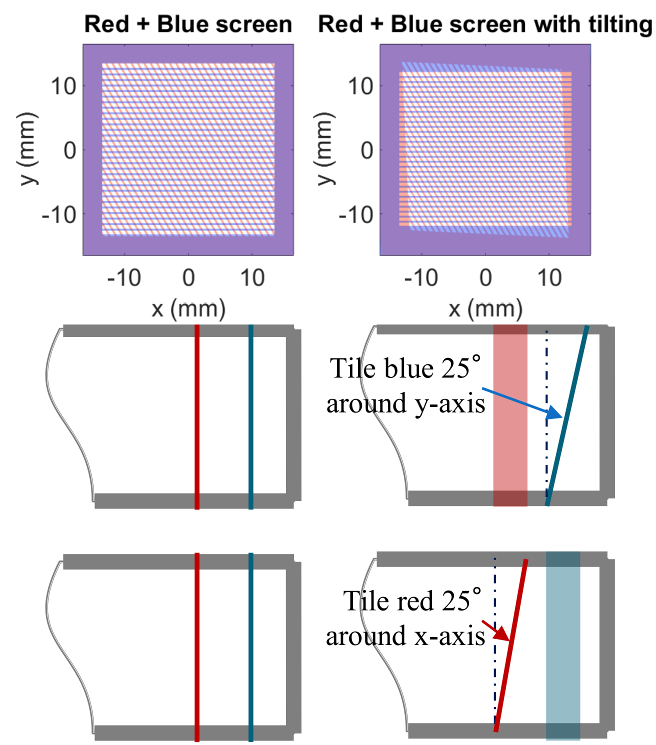
Etched 300um × 300um wire frame



Recent R&D: fully projective SPACAL further improve eff. in forward region





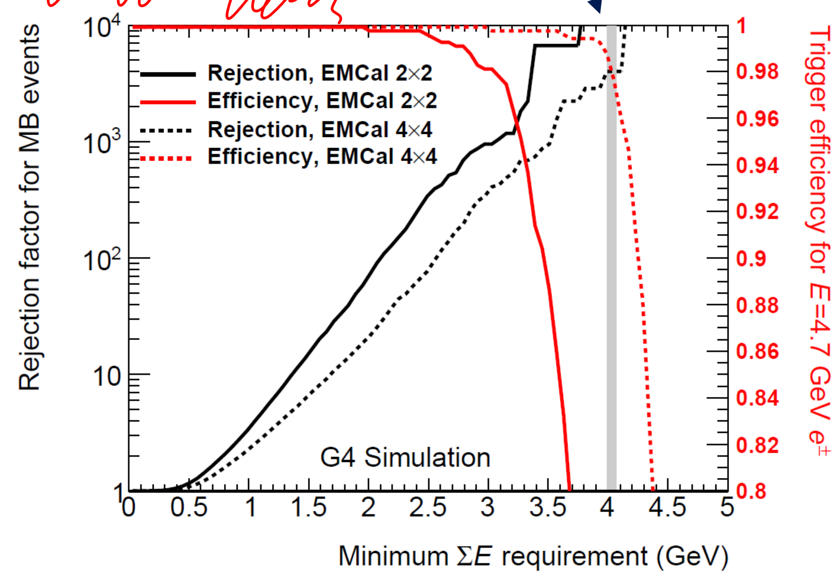


Triggering

- sPHENIX intent to record all MB event in Au+Au collisions, taking advantage of 15kHz DAQ infrastructure at PHENIX
- p+p and p+A collisions will be delivered at higher collision rate
- EMCal tower-sum triggers are studied to select Υ-events in p+p and p+A collisions
- Good efficiency and rejection were demonstrated in full event Geant4 simulations

min dead time

In √s=200 GeV p+p collisions
Expected EMCal 4x4 trigger threshold



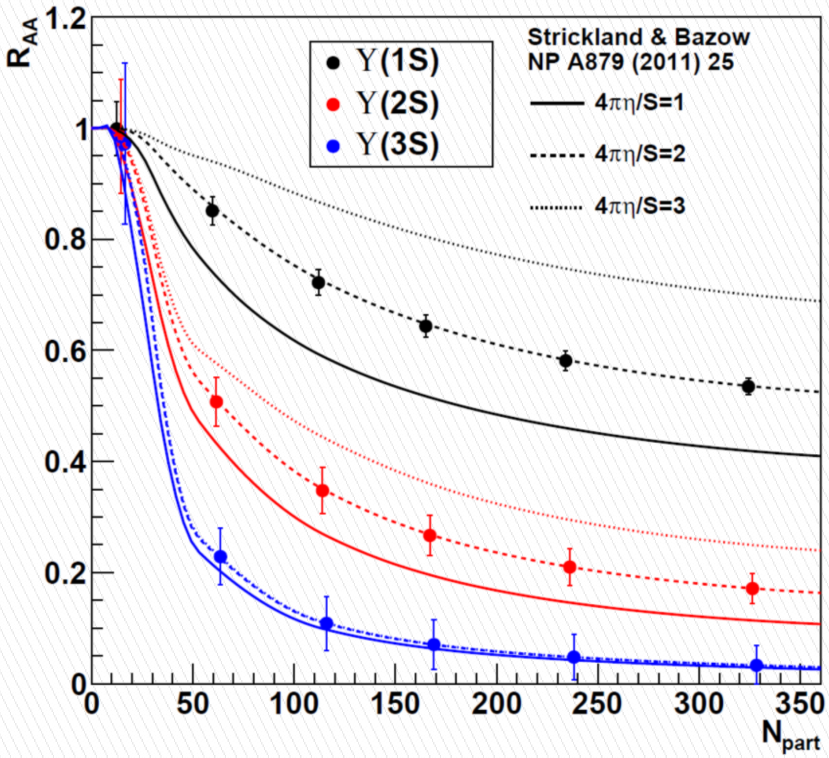
Proposed Running Time

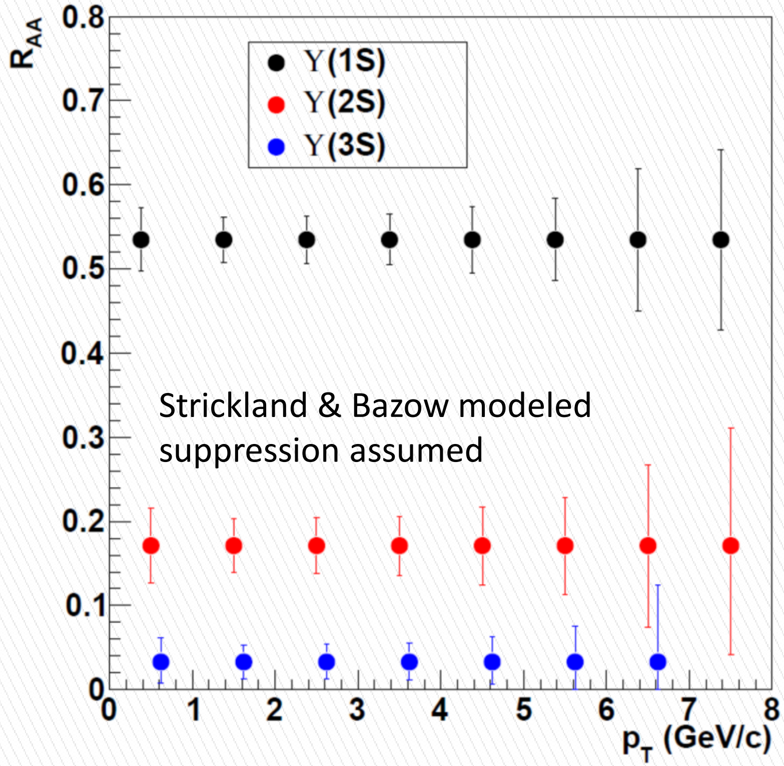
- Baseline sPHENIX program consists of
  - 1 year of commissioning run and 2 years of production
  - 22 week of Au+Au running, 100B MB event recorded
  - 10 week of p+p and p+A each, EMCal trigger used
- Projected yield with detection efficiency applied summarized below

Species	$\int \mathbf{L\,dt}(\mathbf{\|Z\| < 10cm})$	Events	$\langle N_{coll} \rangle$	eID eff.	Υ(1S)	Υ(2S)	Υ(3S) (Before suppression)
$p+p$	$175\ pb^{-1}$	7350 B	1	0.9	8770	2205	1155
Au+Au (MB)		100 B	240.4	0.57	16240	4080	2140
Au+Au (0–10%)		10 B	962	0.49	5625	1415	740
$p+$Au (MB)	$960\ nb^{-1}$	1680 B	4.3	0.84	6560	1650	860
$p+$Au (0–20%)		336 B	8.2	0.8	2360	592	311

Differential Suppression in Au+Au

Stringent constraint to theoretical models over different length scales at RHIC energy

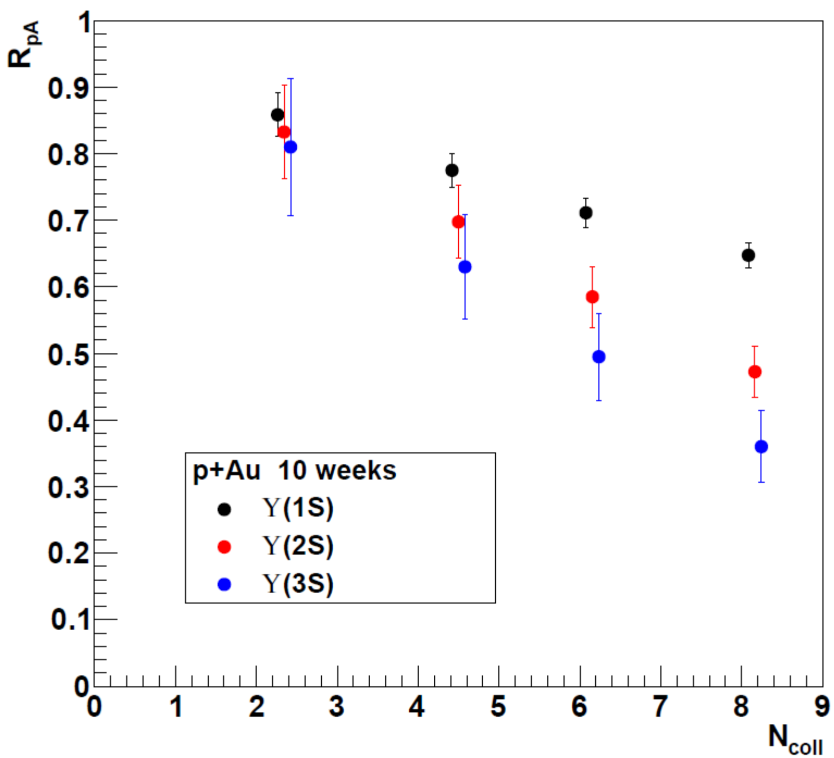




Centrality dependency

pT dependency

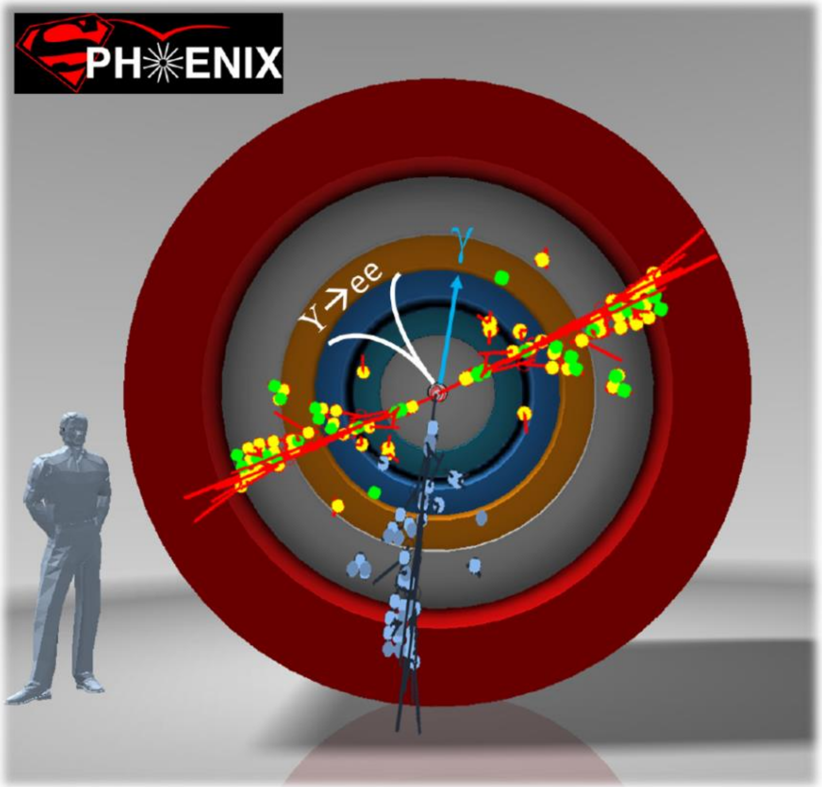
Differential Suppression in p+Au



- Baseline for understanding Au+Au collisions
  + access to Quark energy loss, final state effect, medium effect
- Large pT coverage and 2-unit of rapidity dependency investigates the initial state PDF and energy loss
- At lower binding energy, ϒ(2s), ϒ(3s) tests suppression mechanism in pA in complimentary to LHC and ψ' channels

Conclusion

- sPHENIX – quantitatively study QGP near T_C using probes over a broad range of scales
- Clear separation of ϒ states and high statistical sample allow stringent constraint to theoretical models over different length scales
- Success DOE scientific review on sPHENIX, second review coming in Apr 2015, detailed design and prototyping under way



Summary –
We are fast moving forward

BaBar magnet Transportation
SLAC → BNL, Jan 16, 2015
Also in the news:

Photo by Andy Freeberg, SLAC National Accelerator Laboratory

breaking

January 16, 2015

20-ton magnet heads to New York

A superconducting magnet begins its journey from SLAC laboratory in California to Brookhaven Lab in New York.

By Justin Eure

Extra Materials

Concept for an EIC Detector

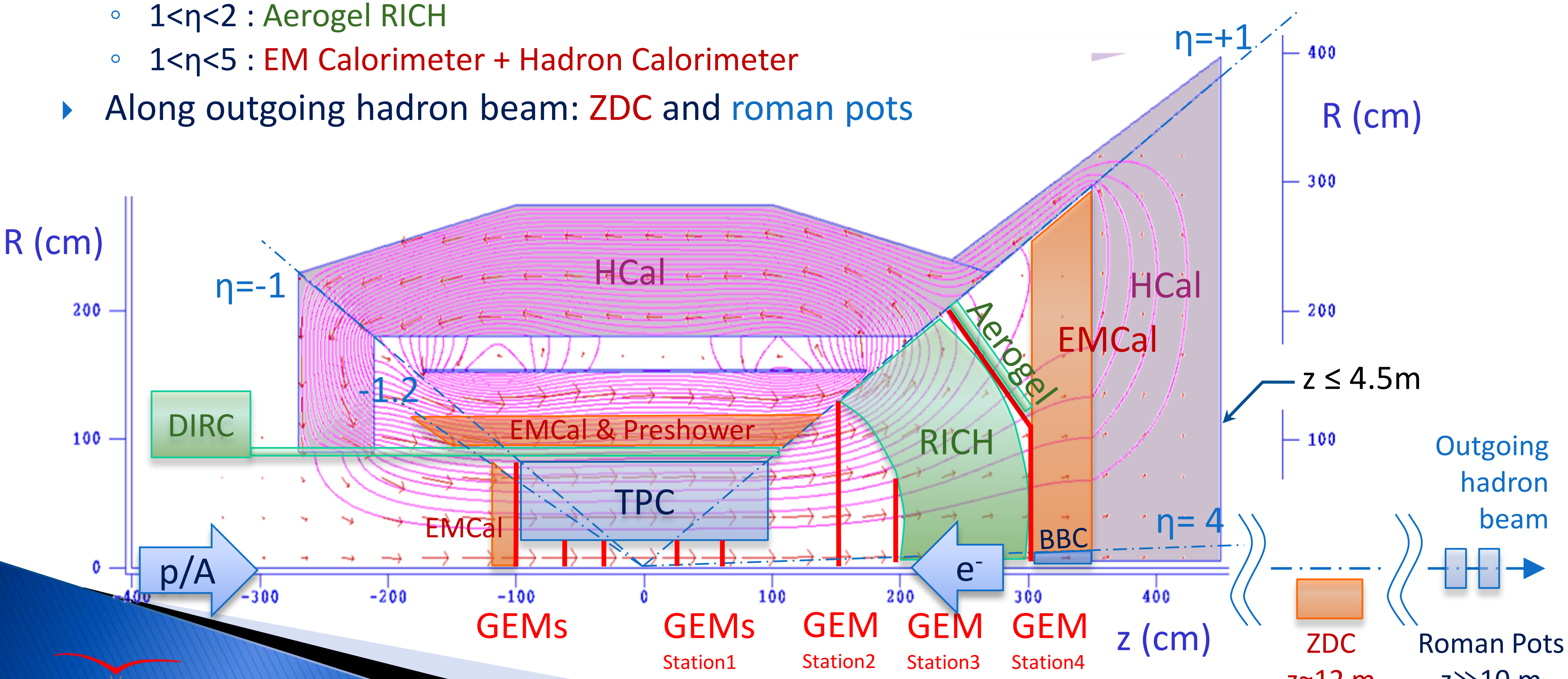
- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC
- -4<η<-1 (e-going) :
  High resolution calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots

Working title: “ePHENIX”

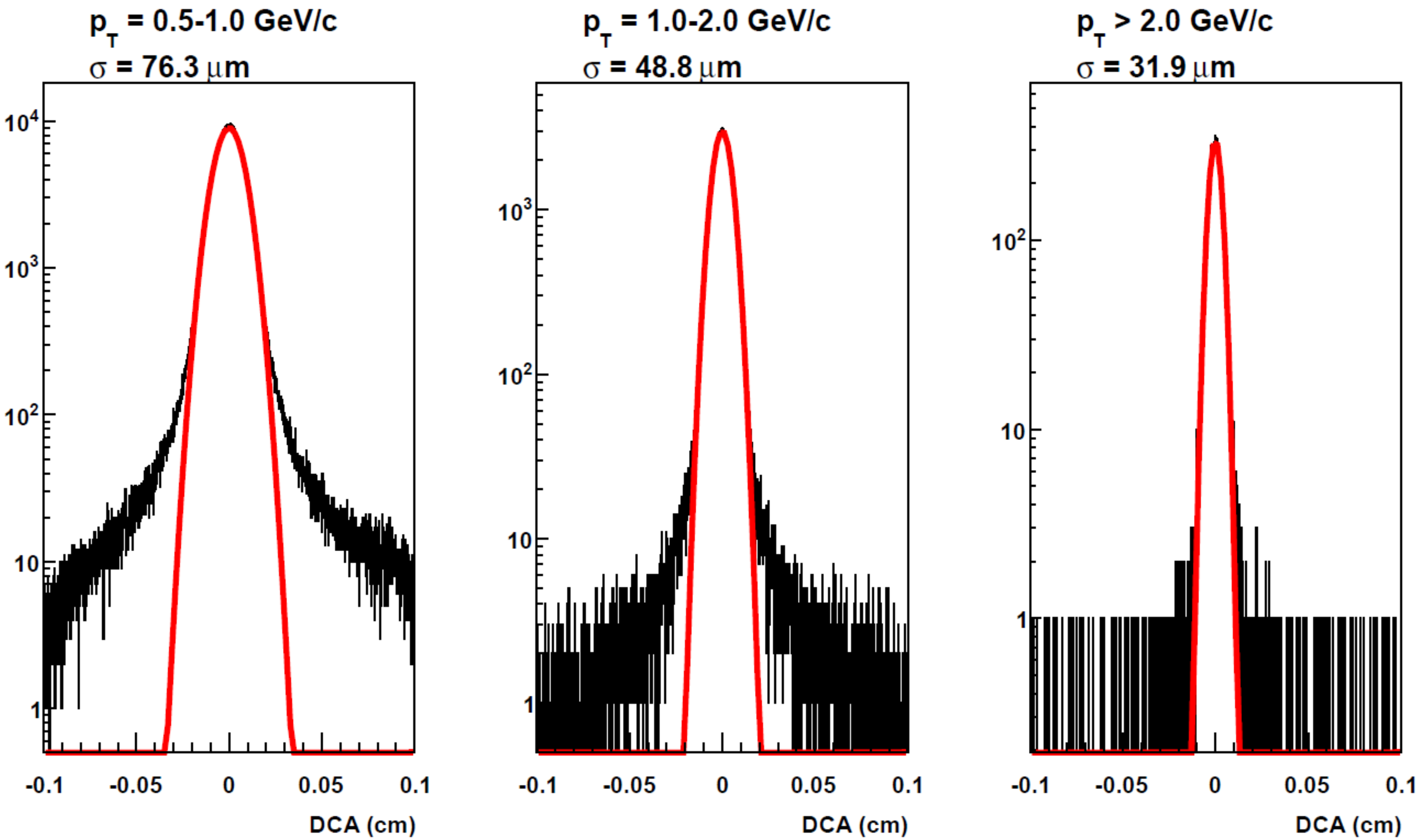
LOI: arXiv:1402.1209

Review: “good day-one detector”

“solid foundation for future upgrades”



DCA resolution



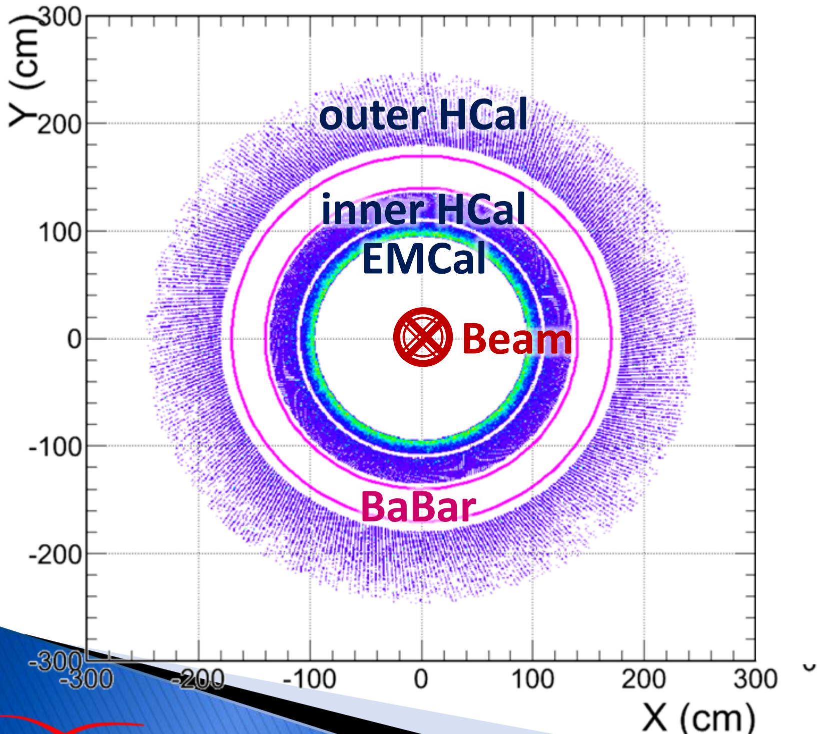
Silicon detector details

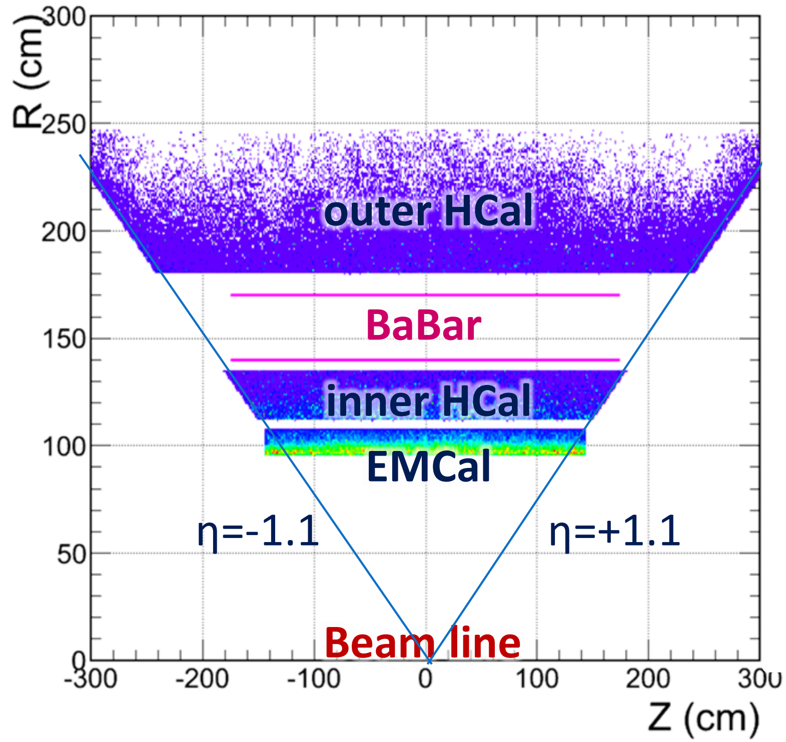
Layer	radius (cm)	sensor pitch (μm)	sensor length (mm)	sensor depth (μm)	total thickness % X_0	area m^2
1	2.7	50	0.425	200	1.3	0.034
2	4.6	50	0.425	200	1.3	0.059
3	9.5	60	8	320	1.35	0.152
4	10.5	240	2	320	1.35	0.185
5	44.5	60	8	320	1	3.3
6	45.5	240	2	320	1	3.5
7	80.0	60	8	320	2	10.8

sPHENIX Calorimeters

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 Cu-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 Steel-Scint. sampling

Calorimeter energy distribution in full event central AuAu collisions and realistic magnetic field





sPHENIX physics program: Critical Knobs to

Temperature dependence of the QGP by **beam energy** variation

Time dependence of the QGP by virtuality variation (**hard process Q^2**)

Length scale within the QGP by interaction hardness (**interaction Q^2**)

Can we observe the strongest coupling near T_c definitively

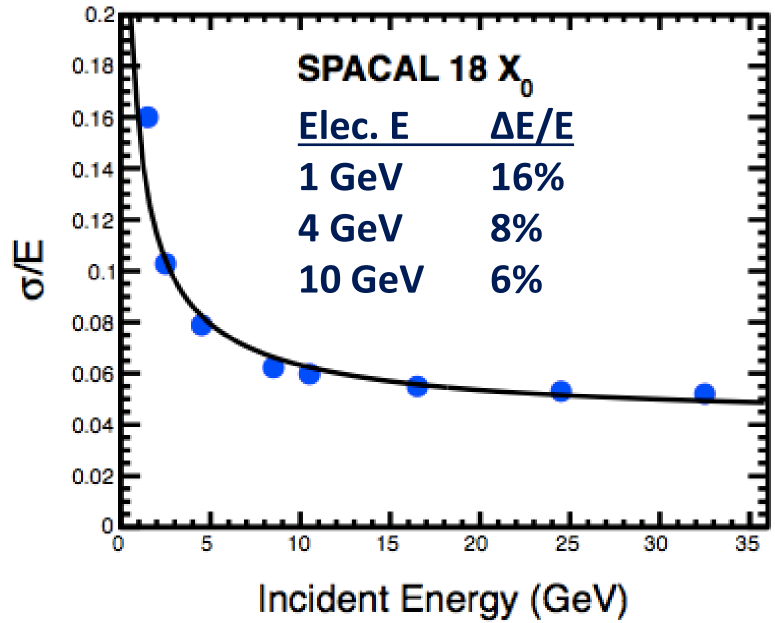
How do the parton shower and medium evolve together?

What are the inner workings? (quasiparticles, fields, modes)

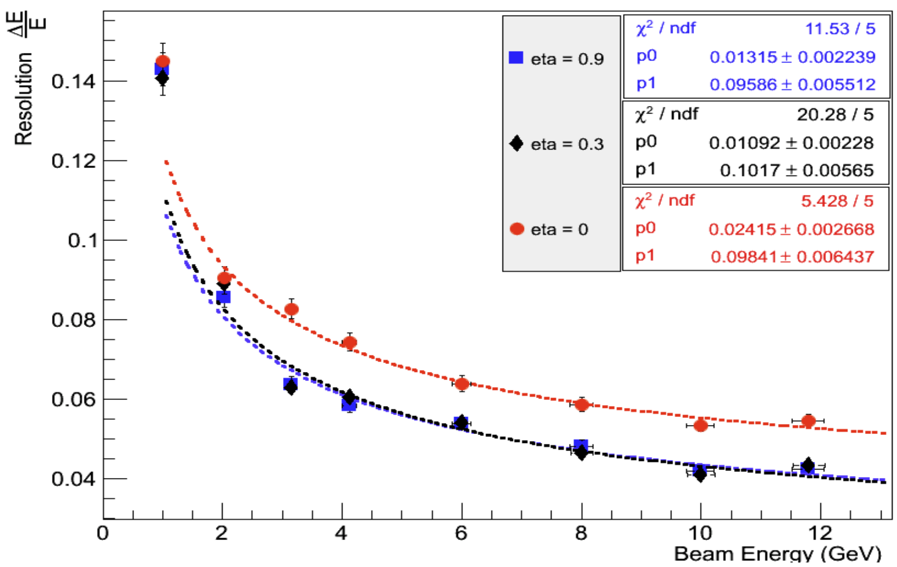
SPACAL study (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general; **more work on noise and cell structure simulation**

sPHENIX simulation
5MeV(scint.)/tower zero-suppression



EIC RD1 study
FermiLab beam tests



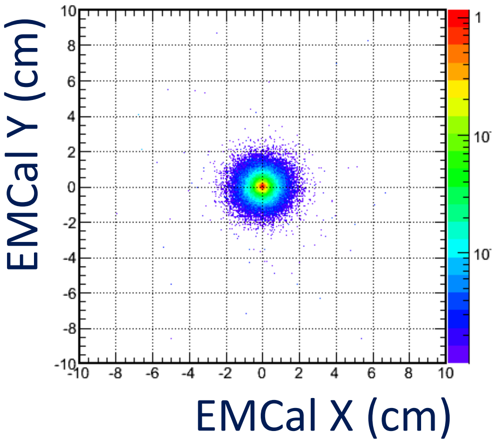
Courtesy: A.Kiselev (BNL)
DIS2014

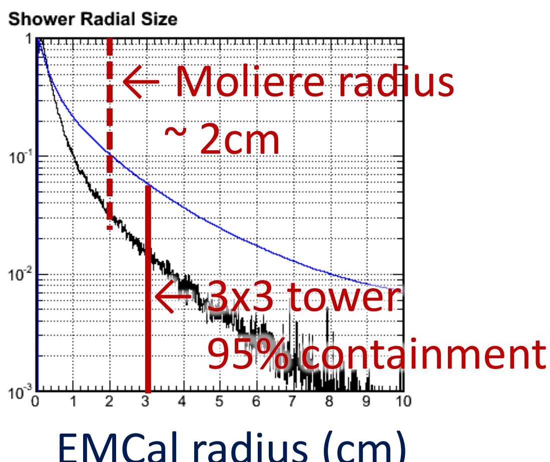
SPACAL study (2): spatial response

- Spacial containment of showers → size of cluster

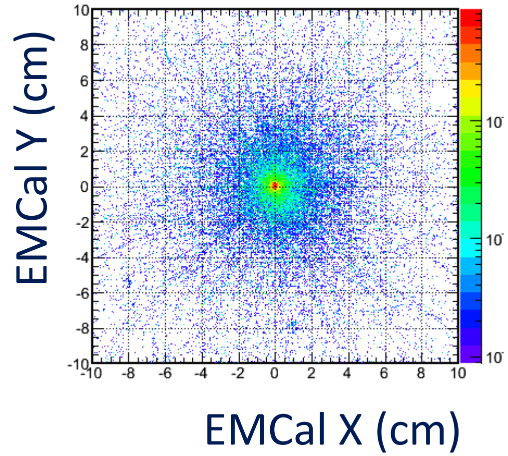
- Energy deposition (A.U.)
- Percentage outside radiu

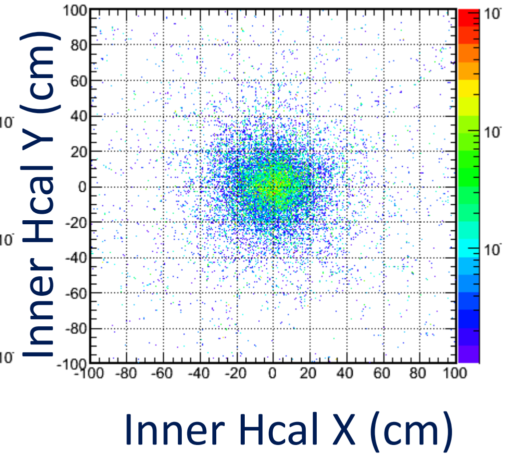
4 GeV Electrons

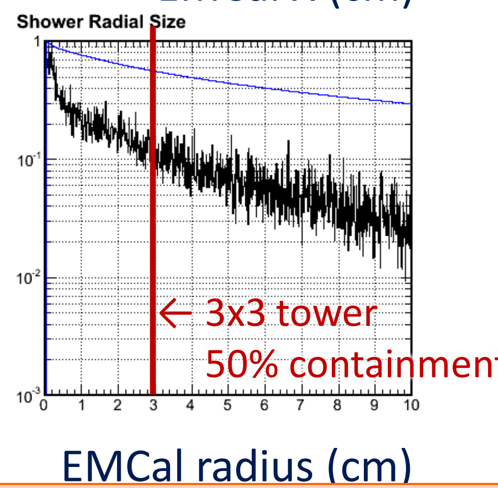


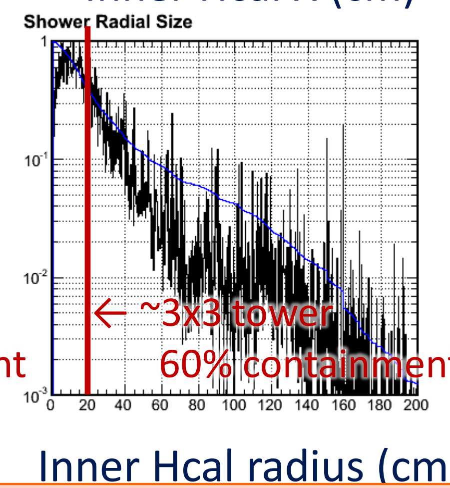


4 GeV Pions, that **passed E/p cut**







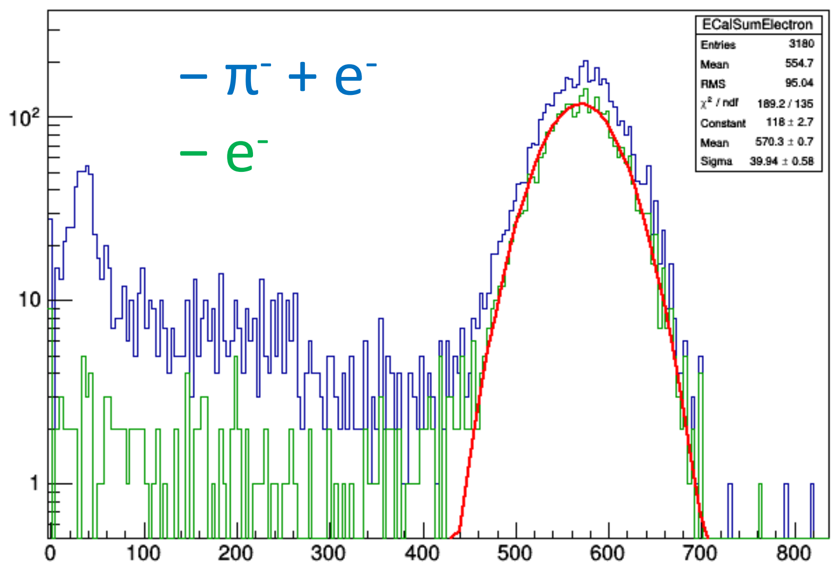


Outtie-HCal has much larger spread. See backup 1

SPACAL study (3): e/pi response

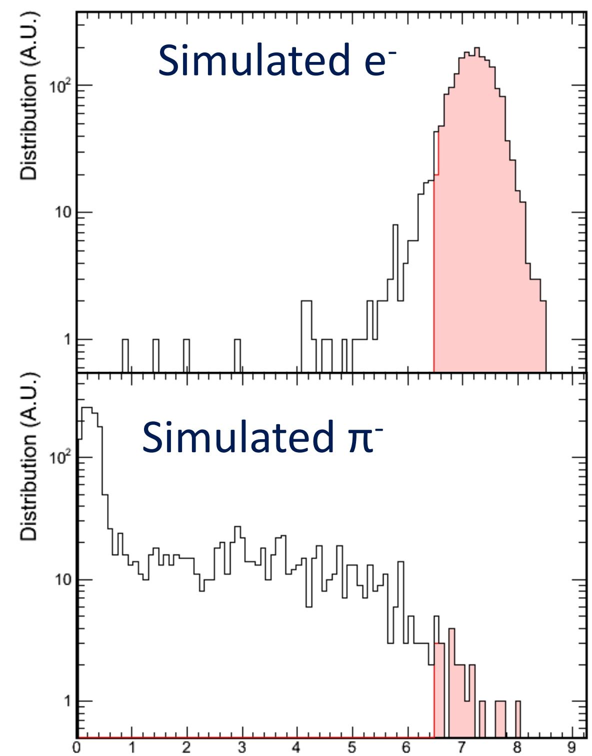
- <u>Pion response → Pion rejections</u>
- **Need to follow up on calibrating hadron simulation to beam tests, e.g. hadron inter. model, Birk's law**

Courtesy : O. Tsai (UCLA)
SPACAL prototypes in 2014 Fermilab beam test
Energy sum for 5x5 towers



Sum energy in 5x5 tower (A.U.)

sPHENIX simulation of 8GeV e/π^-
Energy sum for 5x5 towers



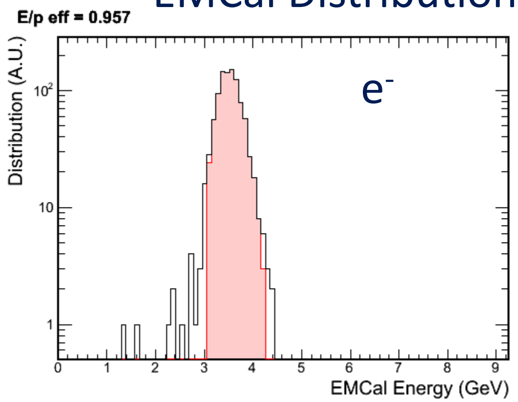
eID and pion rejection in pp : E/p + HCal

4GeV electron and pion-, |η|<0.2

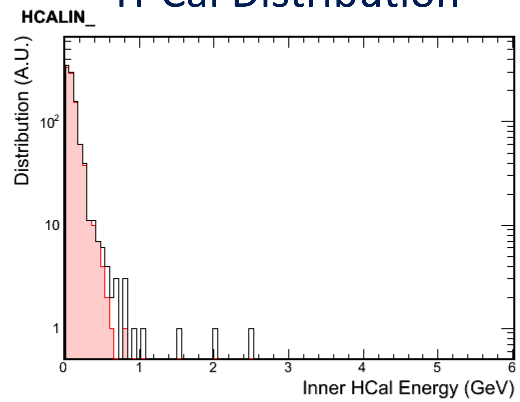
EMCal tower cut : R<3cm, Hcal cut : R<20cm

- all events
- with EMCal E/p cut

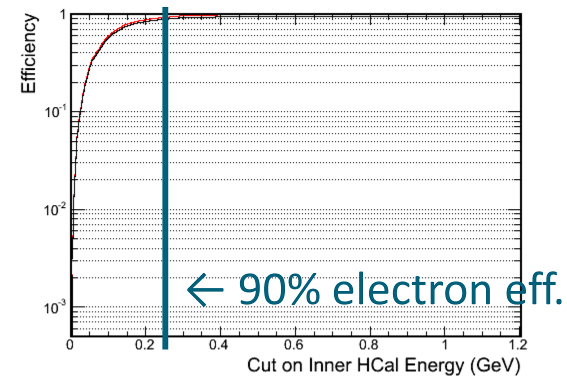
EMCal Distribution



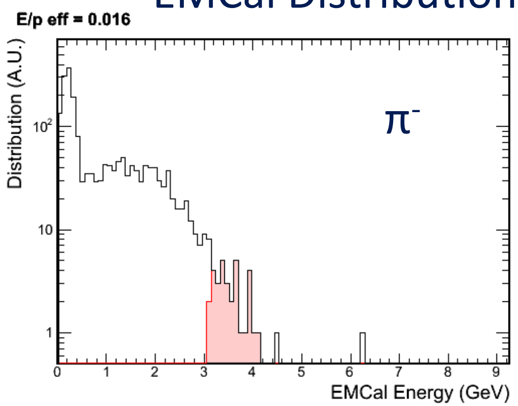
H-Cal Distribution



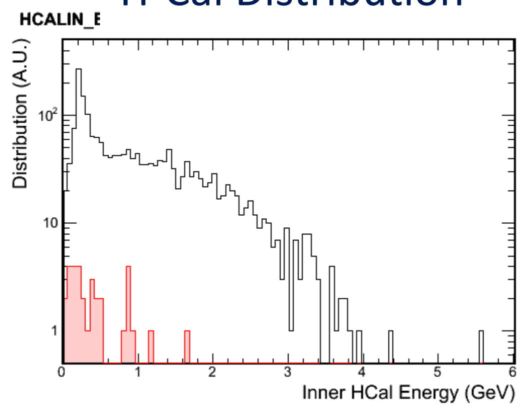
H-Cal Cut Efficiency



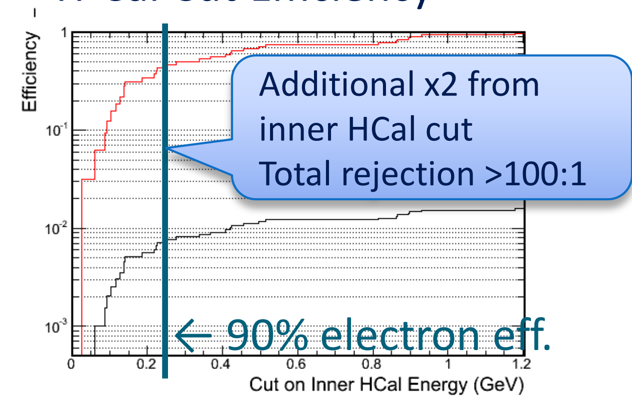
EMCal Distribution



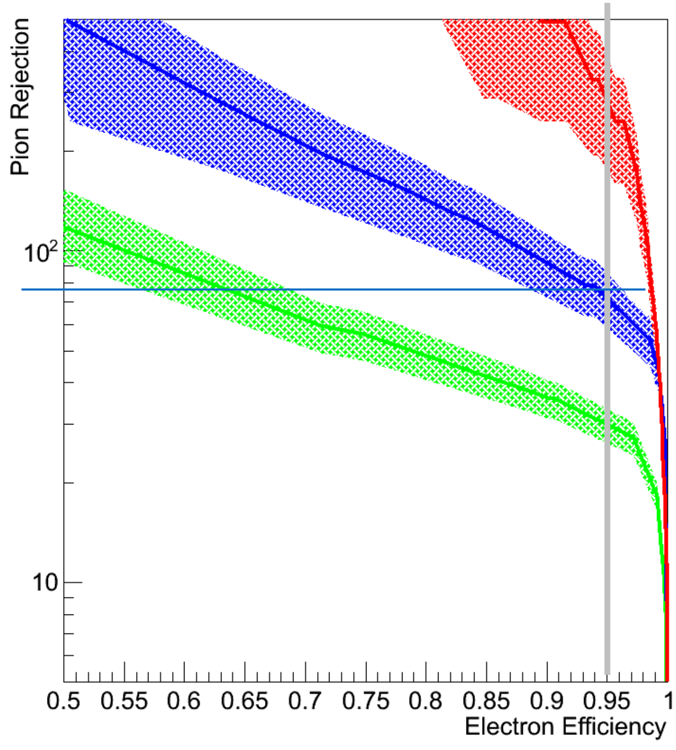
H-Cal Distribution

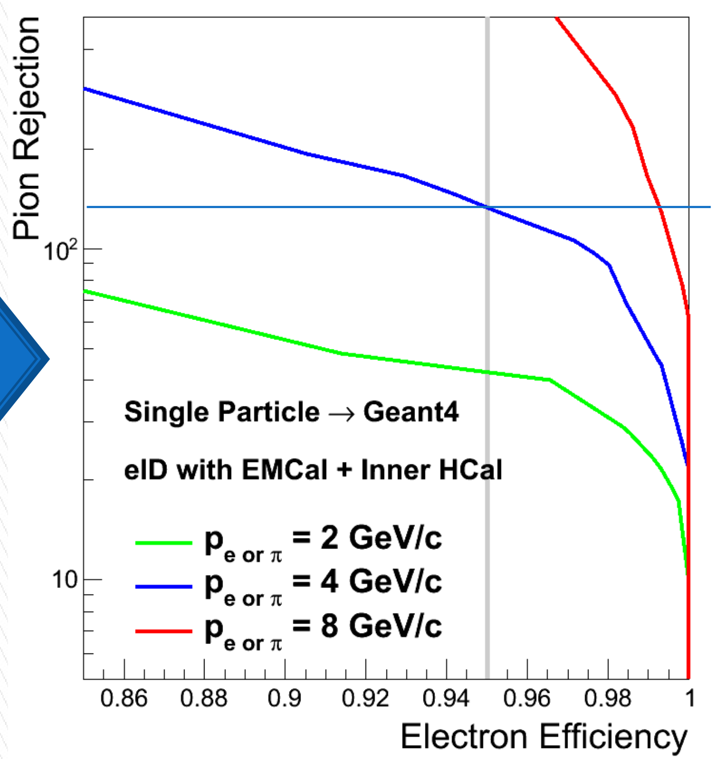


H-Cal Cut Efficiency



Impact of inner HCal





EMCal E/p 1-D likelihood

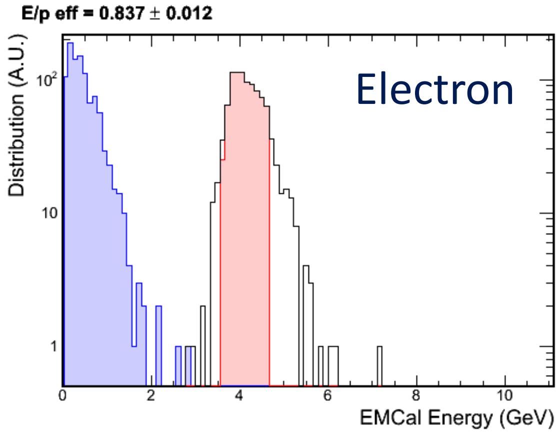
EMCal E/p + Inner HCal 2-D likelihood

eID in central AuAu, central pseudo-rapidity

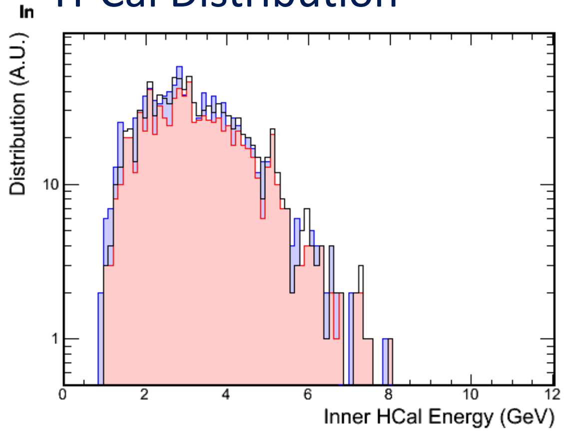
4GeV electron and pion-, $|\eta|<0.2$

EMCal tower cut : R<3cm, Hcal cut : R<20cm

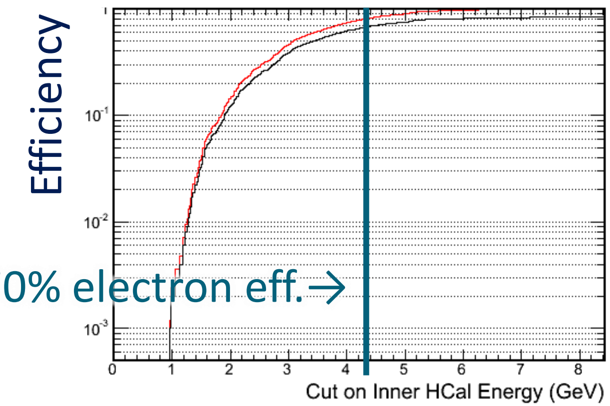
- Hijing background (AuAu 10%C in B-field)
- all c(w/ embedding)
- with EMCal E/p cut (w/ embedding)

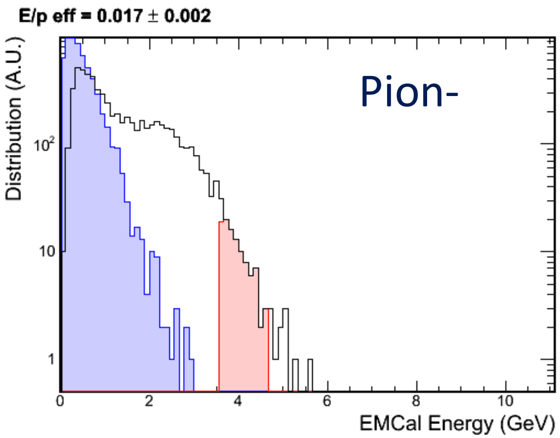


H-Cal Distribution

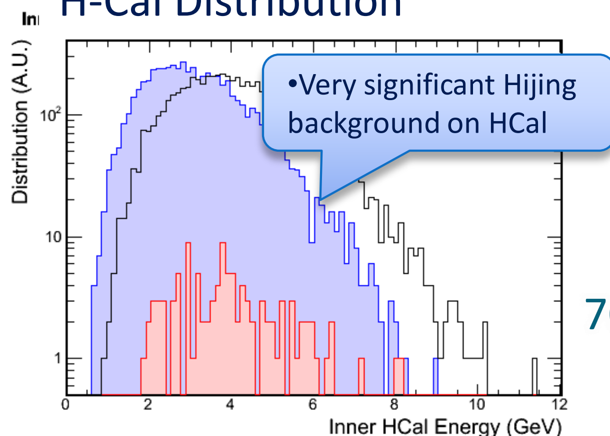


H-Cal Cut Efficiency

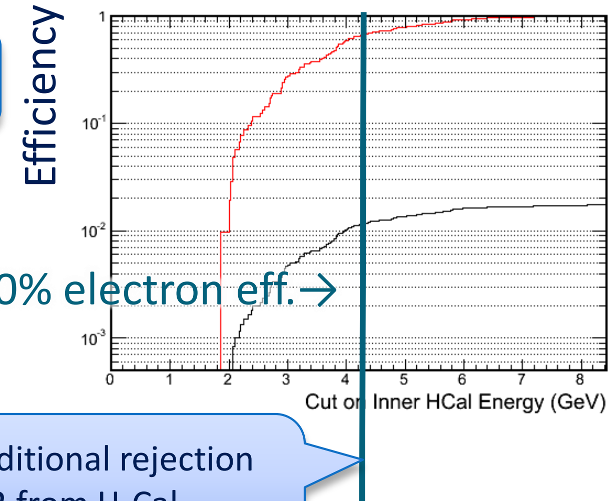




H-Cal Distribution

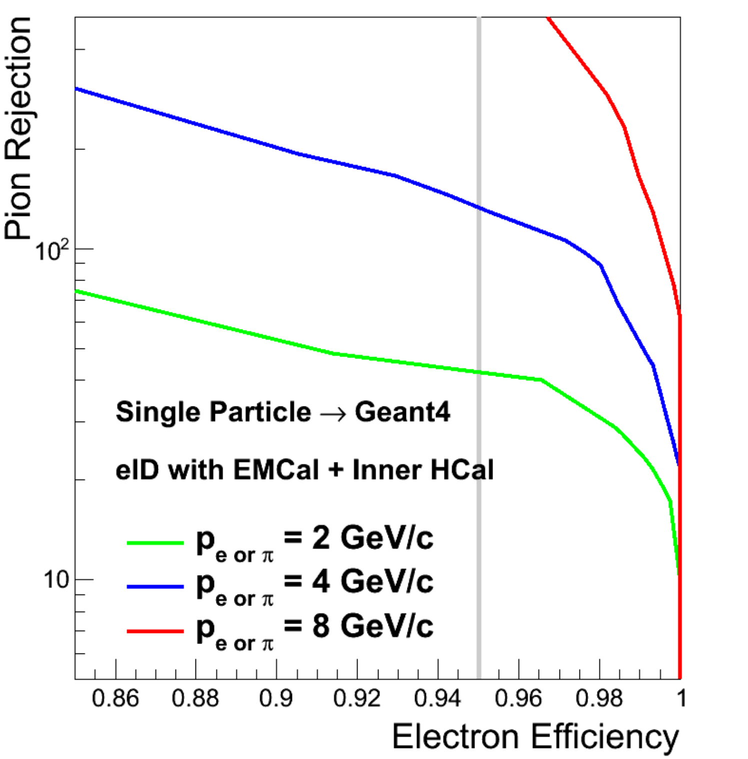


H-Cal Cut Efficiency

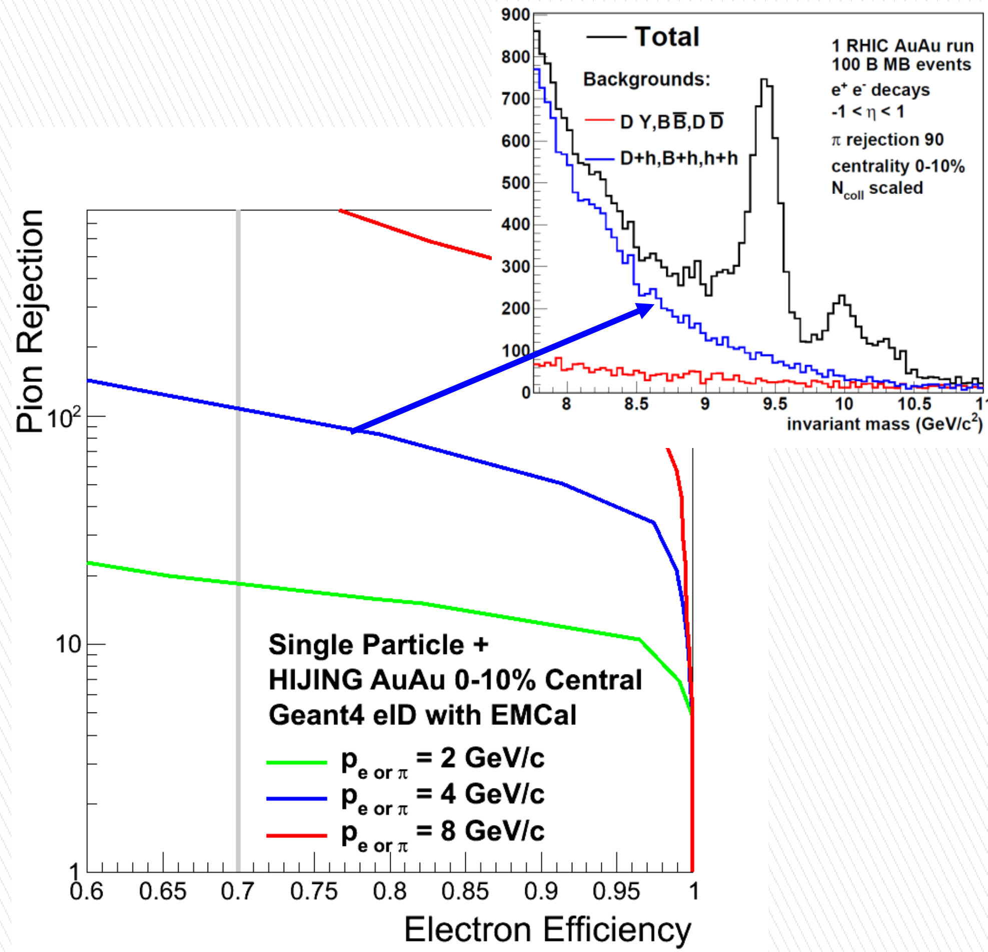


- Additional rejection of x2 from H-Cal
- **Total rejection ~90:1**

Compile everything together for barrel electron ID



pp/ep electron ID (EMC+HCAL)

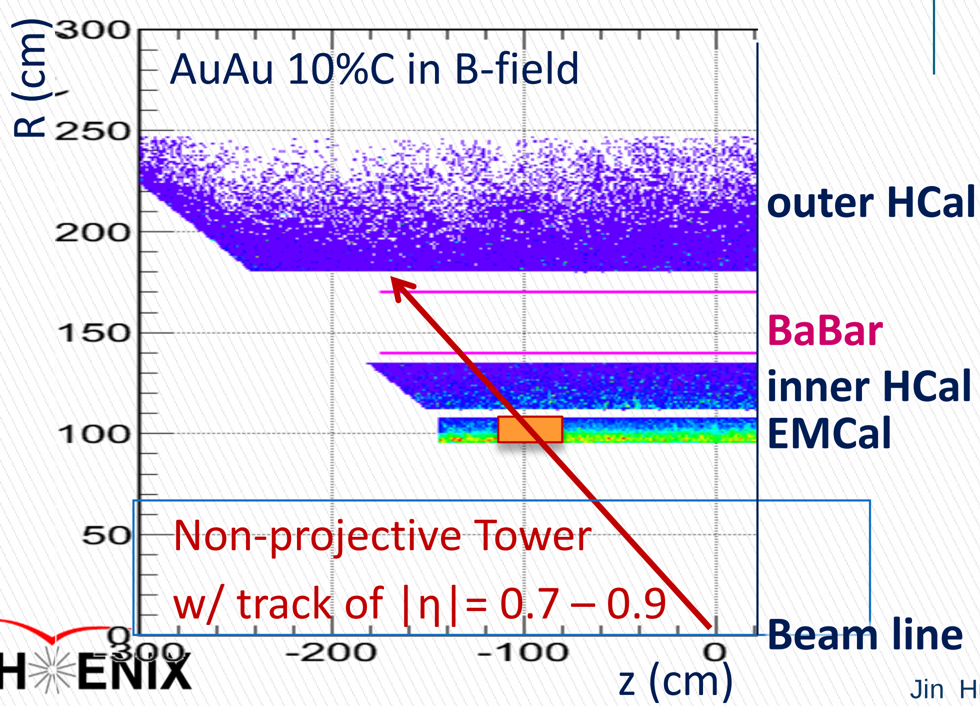


Central AA electron ID (EMC Only)

PHENIX

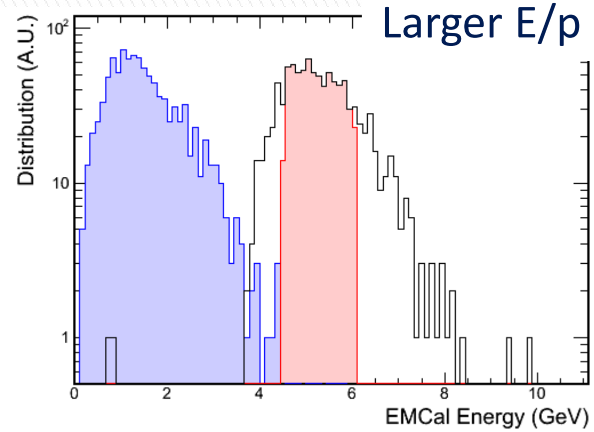
Larger pseudo-rapidity in central AuAu : under study

- Out of the box: larger |η| → larger background
    - Longer path length in calorimeter
    - Covers more non-projective towers
- Many ways to improved in near future
    - **Better estimate of the underlying background event-by-event (improve x1.5)**
    - **Use (radially) thinner ECal (improve x2)**
    - **Shower shape cuts?**
    - **Possibilities for projective towers?**



- all events (w/ embedding)
- with EMCal E/p cut (w/ embedding)
- Hijing background (AuAu 10%C in B-field)

SPACAL e-
Larger E/p cuts



Out of box rejection ~10:1

SPACAL pi- rejection
is lower out of the box